Experimental Investigation and 3D Analysis of Combined Extrusion-Forging Process

A Thesis Submitted in Partial Fulfillment
of the Requirement for the Degree of

MASTER OF TECHNOLOGY

In

Mechanical Engineering

(SPECIALIZATION IN PRODUCTION ENGINEERING)

By

RAVITEJA VINJAMURI
Roll No: 212ME2304

Under the guidance of

Prof. S.K.SAHOO

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA- 769008, INDIA
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DEDICATED

TO

MY PARENTS AND BROTHER

Declaration

I hereby declare that the work which is being presented in this thesis entitled "**Experimental Investigation and 3D Analysis of Combined Extrusion-Forging Process**" in partial fulfillment of the requirements for the award of M.Tech. degree, submitted to the Department of Mechanical Engineering, National Institute of Technology, Rourkela, is an authentic record of my own work under the supervision of Prof. S.K. Sahoo. I have not submitted the matter embodied in this thesis for the award of any other degree or diploma to any other university or Institute.

Date: 2-Jun-14

Raviteja Vinjamuri

DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ODISHA, INDIA – 769008.

CERTIFICATE

This is to certify that, the thesis entitled "**Experimental Investigation and 3D Analysis of Combined Extrusion-Forging Process**" being submitted to the National Institute of Technology, Rourkela by Mr. **Raviteja Vinjamuri**, Roll no. 212ME2304 for the award of M.Tech. degree in Mechanical Engineering, is a bona fide record of research work carried out by him under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements. The Thesis which is based on candidate's own work has not been submitted elsewhere for award of any degree. In my opinion, the thesis is the standard required for the award of M.Tech. degree in Mechanical Engineering.

Prof. S.K. Sahoo
Supervisor
Department of Mechanical Engineering
National Institute of Technology
Rourkela – 769008
Email:sks@nitrkl.ac.in

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Raviteja Vinjamuri
Roll No: 212ME2304
Mechanical Engineering
NIT Rourkela

Date:
Place:

ABSTRACT

Combined extrusion-forging is a metal forming process where the billet is forced through the extrusion and forging dies to get the required product. Combined extrusion-forging processes are now getting importance because of improved mechanical properties, less capital cost, high production rate and less material waste when compared to conventional manufacturing processes like casting and machining. Combined extrusion-forging is used in the manufacturing of a wide range of engineering components. Due to the complexity of the forming process and because of so many process variables, it is difficult to predict the forming load required to manufacture a given component. The present research work emphasizes on the estimation of forming force for combined extrusion-forging process of Collet chuck holder. Experimental studies are carried out to compare the results obtained from the Finite element analysis simulation. Experiments are performed for Collet chuck holder using aluminum billet using required die sets in ambient temperature. Metal flow patterns and filling of die cavities has been studied in the experimental analysis. The modelling has been done by using 3D modelling software Solid works and simulation through the finite element analysis. The results obtained from the simulation results are in good agreement with the experimental results.

Keywords: Combined extrusion-forging, Finite element analysis, Forming load, Simulation

CONTENTS

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NOMENCLATURE

Symbol	Description
σ	Flow stress, MPa
k	Strength Coefficient, MPa
n	Strain hardening exponent
⍰	Strain effective

CHAPTER 1

INTRODUCTION

1.1 Introduction

For the best use of metals, it is generally necessary to shape the metals into required form. Casting is one of the processes for giving the desired shape to metals, but it is not feasible in all cases. Metal forming is another method of shaping metals to desired forms where casting is not desirable. Metal forming is a manufacturing process in which the forces are applied on the material such that stresses induced in the material is greater than the yield stress and less than the ultimate stress so that material is experiencing plastic or permanent deformation to change the shape the component as required. Metal forming can be carried out in the form of either hot working or cold working. Formation of material at a temperature less than the recrystallization temperature is called cold working and if the material is deformed at the temperature greater than the recrystallization temperature and less than the melting point temperature is called hot working. The main difference between cold working and hot working is that residual stresses are produced in cold working but not in hot working. For the same amount of deformation the force and energy required for cold working is higher than the hot working. In the cold working process because the component is not heated, the chances of formation of scales are less, hence closing dimensional tolerances are possible, good surface finish can be obtained and coefficient of friction during the process is less. During hot working operation because the component is heated to a higher temperature, the handling of component is difficult. Rolling, Drawing, Extrusion, Forging, Bending and sheet metal operations like Punching, Blanking, Coining etc., are some of the metal forming process.

Extrusion and Forging are the main metal forming processes used to shape the metal to required shape. Extrusion is a bulk metal forming used to create products of a fixed, crosssectional profile, where the material is drawn through a die to a desired shape at the end of the process. A large variety of complex shapes can be produced through the operation. The process also forms finished parts with an excellent surface finish. In extrusion mainly two types of processes are there. They are forward and backward extrusion processes. In forward extrusion, which is most commonly used process, the ram moves in the same direction of the extruded section and there is relative movement between the billet and the container, leading to high frictional forces. There is a reusable dummy block between the ram and the billet to keep them separated. Friction at the die and the container wall requires higher pressure than indirect extrusion. In this type of extrusion the billet does not move relative to the container, and a die fixed on a hollow ram is pushed against the billet, leading to the flow of the extruded section in opposite direction to the ram movement. The Frictional force on the billet/container interface is thus eliminated during indirect extrusion.

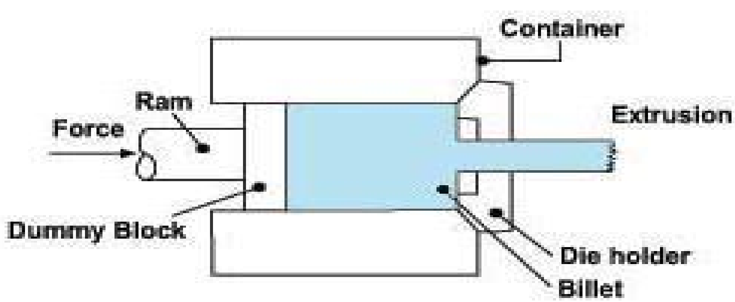


Fig. 1.1: Schematic of Extrusion process [21]

Forging can be defined as the controlled plastic deformation of metals at elevated temperatures into a predetermined size or shape using compressive forces exerted through some type of die by a hammer, a press or an upsetting machine. By definition, forging involves the shaping of metal by the application of impact or pressure, but the primary difference between the various forging methods is the rate at which the energy is applied to the work-piece. Forging is generally employed for those components which require high strength and resistance to shock or vibration and uniform properties. The forgings have high strength and ductility and offer great resistance to impact and fatigue loads due to extra working during the process and the opportunity of aligning the grain flow. Forgings improve the structure of the metal and hence its mechanical properties. The limitations of forgings are high initial cost of dies and their maintenance cost. The rapid oxidation of metal surfaces at high temperature results in scaling which wears the dies.

Open-die forging is a simple and flexible process, it is slow and resulting size and shape of work piece is dependent on the skill of the operator. Closed-die forging or impression die forging, is the shaping of hot metal completely within the walls or cavities of die that come together to enclose the work piece on all sides. Closed die forging can be classified as forging with flash and flash less forging. The flash is an excessive material, which flows out along the parting plane at the end of the operation. Flash generally serves as a part of the die. Flash less forging is used to reduce the cost. It is performed in totally enclosed impressions. The process is used to produce a near-net or net shape forging. The dies make no provision for flash. Flash is the main part in forging process which is used to remove the pressure and for easy flowing of metal. The load required for forging operation also will decrease by using flash in your die design.

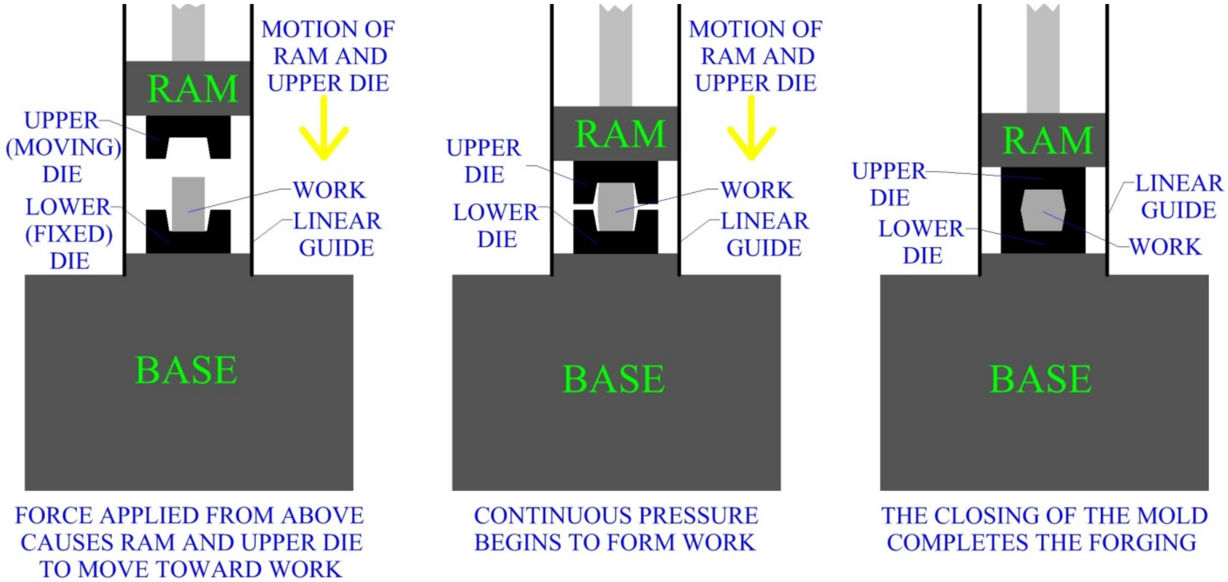


Fig. 1.2: Schematic of forging process [22]

Combined extrusion-forging process is one of the modern manufacturing processes in which the billet is forged by punch through extrusion and forging dies by that our required product will be obtained. In a conventional manufacturing process like casting and machining there is lots of waste material and generally requires more energy, labor and capital compared to forming process. Besides steel, light alloys such as aluminum, zinc and copper and their alloys may be deformed and shaped by the extrusion-forging process due to the advantages of less material wastage, less forming load and good dimensional accuracy. A variety of regular/irregular cross-sections and complex shapes can be achieved by this process. The extrusion - forging process is mainly used in automobile and aerospace applications.

Combined extrusion-forging process is used for the manufacturing of the different shapes like socket wrench, stepped solid shafts, cylindrical cupped parts and conical shafts etc. This process is mainly used in the industries like automotive, aerospace, electrical components and construction equipments etc.

Fig. 1.3: some of the products obtained by using combined extrusion-forging process [21]

1.2 Research Objective

The main objective of the present research work is to manufacture the products with improved mechanical properties, less material wastage and less cost compared to other processes like casting and machining. The other objectives are

- Estimation of forming force for required product shape using combined extrusion forging process.
- Simulation of the Combined extrusion-forging process using FEM (Finite Element Method) based software package DEFORM 3D.
- Designing of dies and setup for the required product shape.
- Performing experimentation using aluminum as a billet on INSTRON-600 KN universal testing machine.
- Comparing the results obtained from Experimental investigation and simulation process.

1.3 Thesis Outline

Chapter 2: Literature Review

This chapter includes the study of previous research work which is done on the topic combined extrusion-forging process. The present problem had been derived form the literature review.

Chapter 3: Finite Element Analysis

This chapter deals with the simulation of the Finite element analysis for combined extrusion-forging process of Collet chuck holder. Effective strain, Effective stress, Velocity and metal flow patterns have been analyzed.

Chapter 4: Experimental Analysis

This chapter deals with the design of the experimental setup for combined extrusion-forging process. The product Collet chuck holder was made at different punch movements. Also determination of stress-strain characteristics and friction factor of aluminum has been calculated.

***Chapter 5*:** Comparison of Results

This chapter deals with the comparison of results obtained from the experimental and simulation analysis.

Chapter 6: Conclusion and Scope for Future work

This chapter deals with the conclusion obtained from the present research work and scope for the future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The main challenge faced by current manufacturing industry is to produce the parts with higher strength with less cost and more fatigue resistant, etc. Combined Extrusion-Forging is one of such processes which produces complex product shapes with higher mechanical properties and higher productivity compared to other processes such as casting and machining. Many researchers have carried out a series of investigations on combined extrusion-forging process. The following are some of the literature review carried out during my project.

2.2 Study of previous Research work

Chitkara and Aleem [1] developed a generalized slab method for analysis of the extrusion of axi-symmetric bi-metallic tubes through the profiled shaped dies and over profile shaped mandrels. An experimental investigation into a forward extrusion of bi-metallic tubes made of aluminium and copper were also carried out and the resultant non-dimensional extrusion pressures, flow patterns and characteristic modes observed and found reasonable good agreement with theoretical calculation. Brayden et.al [2] presented an analysis that Neutral radius is critical in the analysis of extrusion-forging process. Neutral radius (R_n) was always found to occupy a position so as to achieve a minimum energy dissipation state and overall constancy of volume and load equilibrium. Vickery et.al [3] done an investigation that die hole influence the behavior of the workpiece material. The material having a larger die hole will fill first and transition also occurs first. Monaghan et.al [4] presented an analysis that The energy required to overcome friction showed a steady increase throughout deformation particularly during stage-3, which suggests that proper lubrication required to reduce forging load.

Giardini et.al [5] has carried out an experimental investigation on the influence of die geometry and friction conditions on formability in extrusion-forging. By hat investigation, he suggested that the designer uses raft project to identify the most critical zone in dies. Lin et.al [6] has carried out an experimental investigation on the influence of the geometrical conditions of die and workpiece on the barreling formation during extrusion-forging process. He suggested that due to condition of volume consistency, radii of curvature in top and bottom barrels are increased as the taper angle or the aspect ratio is increased. But these radii are increased as the diametral ratio is decreased. Kar et.al [7] has done an investigation on upper bound analysis for extrusion of the T-section bar from square billet through square dies. From the investigation, he concluded that optimized extrusion pressures were found out. Extrusion pressure progressively decreases at each area reduction as the ratio of flange to web thickness decreases from 1.2 to 0.8. Kim et.al [8] has carried out an experimental investigation on upper bound analysis of the torsional backward extrusion process. He suggested a kinematically admissible velocity field has been proposed by using stream function. The deformation force an be reduced by 30% compared with conventional backward extrusion.

Hwang et.al [9] analyzed that proposed velocity fields the extrusion load and the average extruded length have been determined by minimizing the total power with respect to optimizing parameters. Sahoo et.al [10] investigated that Optimal die geometry can be obtained for different area reductions and friction conditions. Yamin et.al [11] done experiments on cup rod combined extrusion process of magnesium alloy (AZ61A).Experiments shown that parts of AZ61A could be produced by isothermal extrusion and appropriate lubricant greatly reduce the forming load. Narayana swamy et.al [12] done an experimental investigation on barreling of aluminum alloy billet during extrusion-forging using different lubricants and he concluded that All values of stress increases with the increase in approach angle under plane and tri axial condition. The rate of change of barreling radius w.r.t. hydrostatic stress is different for different approach angle.

Farhoumand et.al [13] had done an analysis that Finite element method has been used to investigate the effect of geometrical parameters such as die corner radius and gap height as well as process condition such as friction on the process. Paltasingh et.al [14] has done simulation and experimental analysis on Lateral extrusion of square and the pentagonal head from round shaft. By comparing the simulation and experimental results he concluded that by the increase in volume of die cavity the forming load also will increase and corner filling takes place first at the bottom of the die cavity during the steady state and then the flow proceeds towards the top corners of the die. Bakshi - Jooybari et al. [15] proposed a combined upper bound and slab method for estimating the deformation load for cold rod extrusion of aluminium and lead in an optimum curved die profile. The experimental results validate the finite element results that obtained by commercially available finite element software, ABAQUS. It was illustrated that the extrusion load in the optimum curved die during the deformation is considerably less than that in the optimum conical die. Choi et al. [16] have proposed a kinematically admissible velocity field for the forging of a trochoidal gear using an aluminium alloy. A neutral surface has been used to represent the inward flow of material during the forging operation using a hollow billet with a flat punch. It was found that the theoretical solutions were useful in the prediction of the forging load for the forging gears.

Shinchun et al. [17] have done a study of cup-cup axisymmetric combined extrusion by the upper-bound approach where the upper-ram pressure is estimated at different stages of deformation and found that the flow pattern (simple forward extrusion, simple backward extrusion and forward and backward extrusion) are mainly affected by the combination of the reduction in area of the forward extrusion part and that of the backward extrusion part. While taking into consideration the deformation stages (the early stage and the final stage) and the flow patterns of all the three extrusions, the analytical results agree quite well with the experimental results. Lee et al. [18] have developed a kinematically admissible velocity fields for both forward and backward extrusion processes of hexagonal and trochoidal wrench bolts. Extrusion loads and extrusion lengths have been determined minimising the total power with respect to optimizing pseudo-independent parameters. Theoretical predictions are in good agreement with the experimental results. Therefore, the proposed velocity fields can be used for the prediction of the forming load and extruded length in the combined extrusion process of hexagonal and trochoidal shapes wrench bolts. Gouveia et al. [19] stated that the upper bound method failed to provide a general theoretical route for the optimal die design and process control of three dimensional extrusion shapes. Experimental results confirm that physical modelling is capable of providing relevant quantitative information on the behavior of a complex. 3D extrusion process, especially strain distribution. Updated lagrangian finite element numerical simulations show a good agreement with the results of the replicating the flow pattern and the distribution of strain.

2.3 Present problem

From the above literature review, we can observe that there is a lot of research work has done on the topic combined extrusion forging process. Many researchers analyze the extrusion-forging process for different products. But in present research the products which are manufactured from machining or casting are taken for producing using combined extrusion-forging process. In present research work, Collet Chuck Holder is taken as the product which is manufactured using extrusion-forging process and analysis has been done by DEFORM 3D software. Collet chuck holders are special tool holders which use collets to hold the cutting tools in place. Such holders use the collet, collet nut and the tool holder to properly secure the cutting tool. As the nut is screwed on, it compresses the collet spring onto the cutting tool. These devices are used as holding devices for work piece or cutting tool on CNC lathes and milling machines. They are suitable for drilling, milling, tapping and boring application.

CHAPTER 3

FINITE ELEMENT ANALYSIS

3.1 Introduction

Finite element analysis consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in the designing of new products and improvement of existing product design. Traditionally, the metal forming process that produces an acceptable product has been accomplished by extensive previous experience and an expensive and time consuming cycle of trails, evaluations and redesign. Such a traditional forming design approach is rapidly being replaced by more efficient computer simulation. There are various metals forming analysis software that can realistically simulate material forming processes. Among them, DEFORM 3D is one, which is popular among the researchers and industries. DEFORM 3D is a powerful simulation software designed to analyze the three dimensional flow in the complex metal forming process and metal cutting problems.

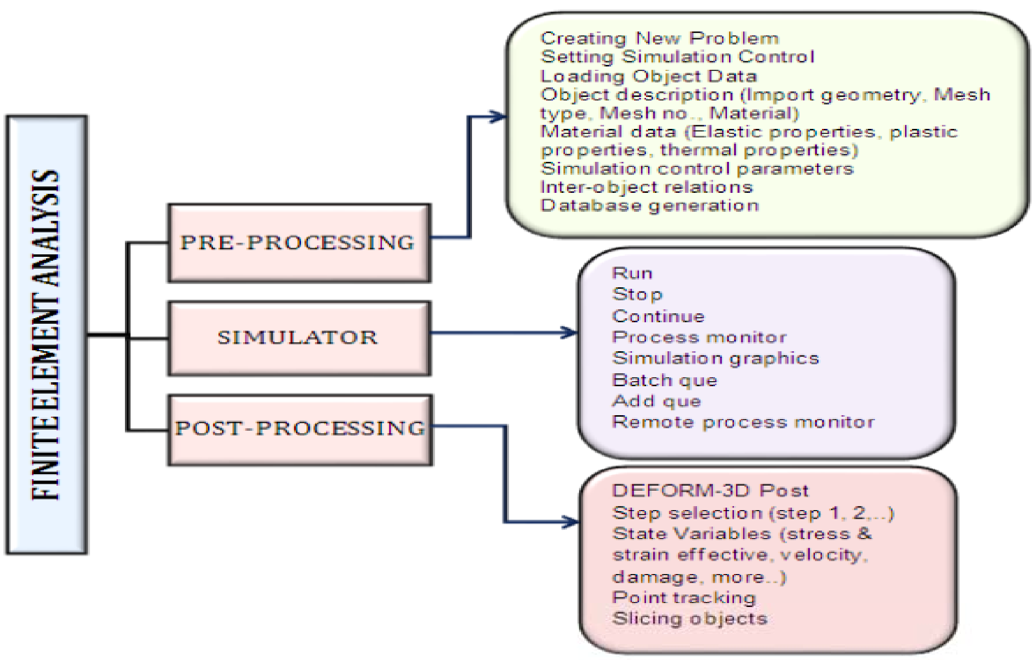


Fig. 3.1: Major components of FEM simulation for combined extrusion-forging process [23]

The simulation software mainly consists of three major components pre-processor, simulation and post processor as shown in Fig. 3.1.

3.2 Pre-processor

The pre-processor is used for taking the input parameters like temperature, coefficient of friction, material data, etc. The input like billet, punch and die have been done in 3D modelling software called Solid works. These solid models are directly imported to pre-processor for forming process analysis. By using this input data pre-processor will generate one database file which is used in the simulation process. The major input parameters required in pre-processor are shown in Fig. 3.2.

The following are the steps to follow in Preprocessing stage

3.2.1 Simulation control

In this, units were changed to the SI system. Lagrangian incremental type simulation followed during the process.We should give starting and stopping criteria for the simulation process in this section. In the 'step' section we will give the number of simulation steps required to complete the product. The length of travelling of the punch or number of simulation steps was taken as a stopping criteria.

3.2.2 Materials

Isotropic and rigid-perfectly plastic material type was used. The commercially available aluminium is chosen as the material. The flow stress of the material is taken as 132 MPa which is taken as experimental value.

Major input requisite for simulation is listed below:

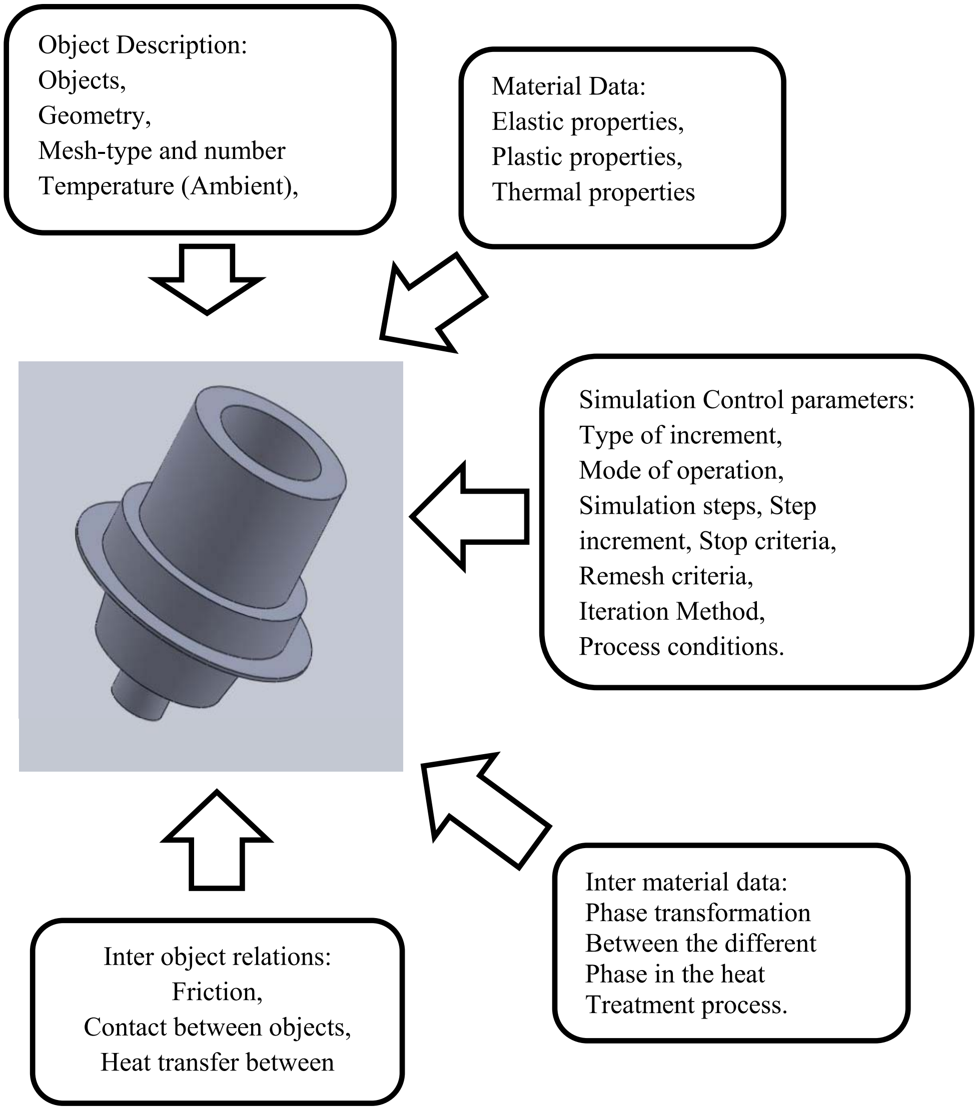
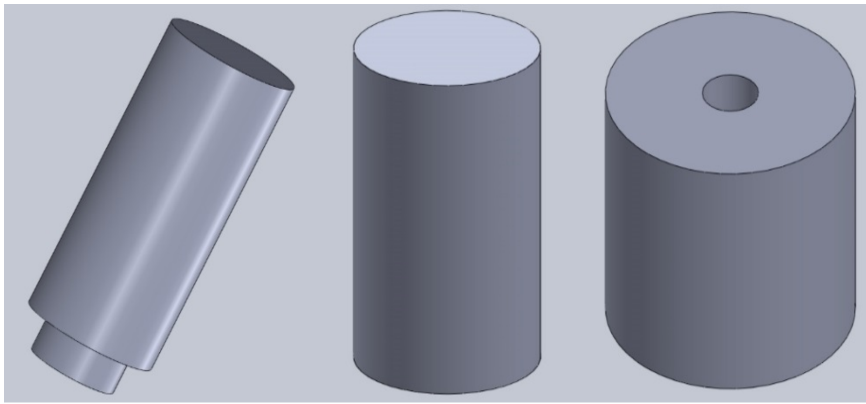


Fig. 3.2: Major input parameters required simulation process

3.2.3 Object Description

In this section, the three objects billet, punch and die were imported from the modelling software as *.stl* files. The solid models of billet, punch and bottom die are shown in Fig. 3.3. Here billet is chosen as plastic and punch, die were chosen as rigid objects. Punch was taken as primary die which compresses the billet. 20,000 mesh elements were considered during the meshing process. Ambient temperature was considered for simulated process because it is a cold working process.



(a) Punch (b) Billet (c) Bottom Die

Fig. 3.3: Objects required for simulation process.

3.2.4 Inter Object Relations

The purpose of inter object relations is to define the relation between the different objects in the simulation process. The objects which come in contact during the course of simulation process must have a contact relation defined. Punch, or the primary die is defined as the master die and the billet is defined as slave object. In our simulation process, we define friction factor values as a contact relation. This friction factor value is 0.19 which is available from the experimental results.

3.2.5 Movement control

Movement controls are applicable to rigid objects like punch and bottom die. By using these controls we can keep the three objects in correct position for compression process.

3.2.6 Boundary condition

The top die or punch movement is only in –z direction. There was no movement of bottom die and billet.

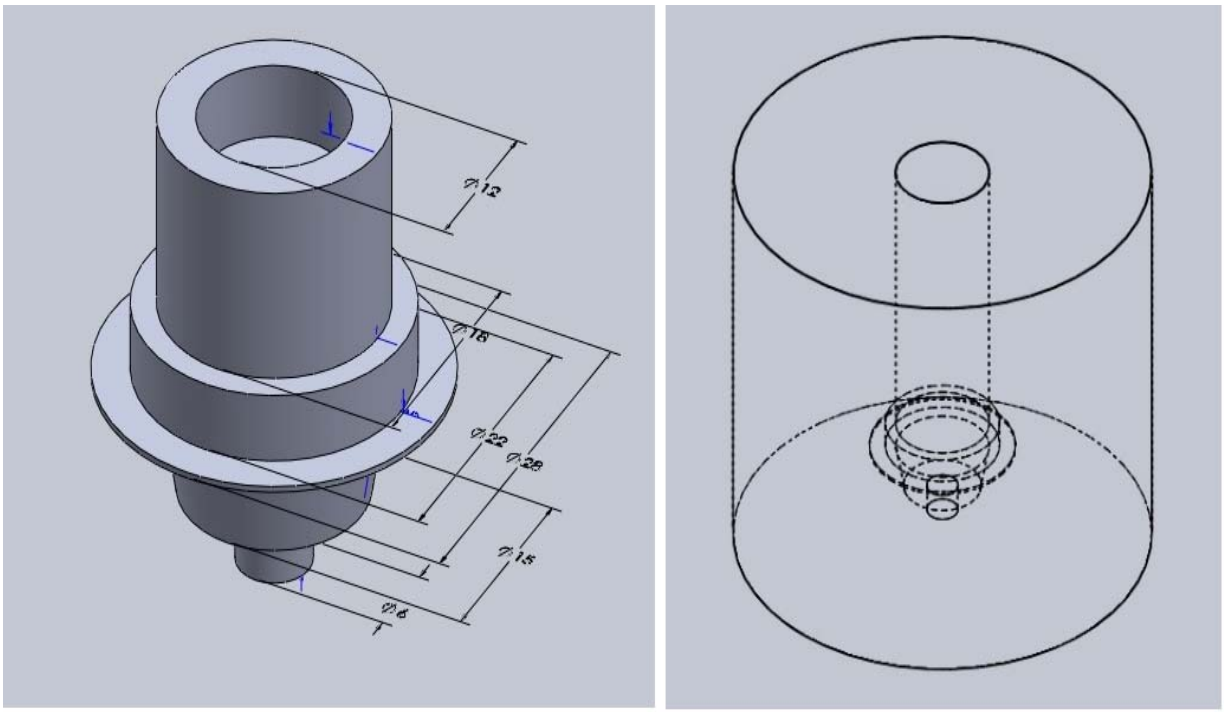


Fig. 3.4: Die design using the dimensions of Collet chuck holder

Table 3.1: Process parameters used in the simulation

Billet length	37 mm
Billet diameter	15 mm
Billet temperature	Ambient
Punch speed	0.3 mm/s
Friction factor	0.19
Flow stress	132 MPa
No. of mesh element	20000
Average strain rate	1/s
Limiting strain rate	0.01/s

The above Fig. 3.4 shows the dimensions of required product Collet chuck holder. From this we can design the required die for simulation process using 3D modelling software. Table 3.1 shows the different process parameters used in the simulation process. These parameters were used in the pre-processor section.

3.3 SIMULATION

The simulation engine will perform the numerical calculations required to analyze the process, and write the results to the database file. The simulation engine reads the database file which is coming from the preprocessor and it calculates the solution for the given simulation problem. According to input data the finite element simulation performs the numerical calculations to solve the problem. The simulation engine will run till it satisfies the stopping criteria which are mentioned in the preprocessor simulation controls. After stopping the simulation engine required product will be obtained from post processor. The Fig. 3.5 shows the punch, billet and die assembly set up before and after the simulation process.

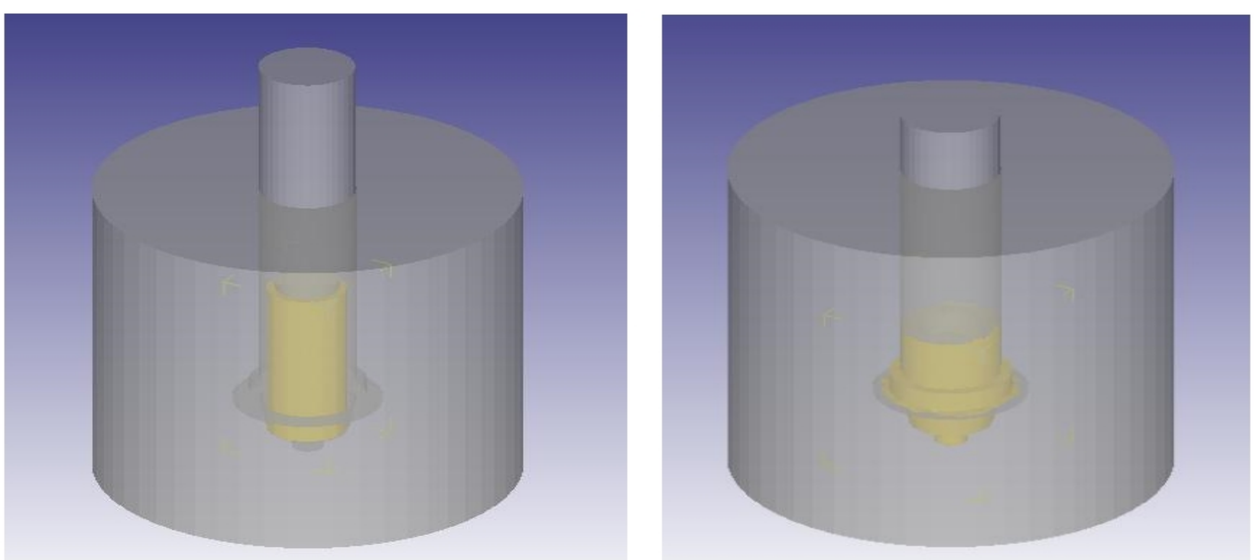


Fig. 3.5: Assembly of objects before and after simulation

3.4 POST PROCESSOR

The post-processor is used to view and extract data from the simulation results in the database file. From post processor we can obtain stress, strain, final geometry of the object, and graphs between different parameters and the different steps in forming process etc. Information which is available from the post-processor includes:

- Deformed geometry, including tool movements and deformed mesh at each saved step.
- Line or shaded contours display the distribution of any state variables, including stress, strain, temperature, damage, and others.
- Vector plots: displacement and velocity vectors indicate magnitude and direction of displacement or velocity for every node at each step throughout the process.
- Graphs of key variables such as press loads, volumes, and point tracked state variables.
- Flow net for showing the metal flow patterns in simulations.
- Point tracking to show how material moves and plots of state variables at these points.

3.5 Results and Analysis

Results obtained from the simulation process of combined extrusion-forging for Collet chuck holder are discussed and summarized. Simulation is carried out for different punch movements. Here are the results for extrusion-forging process effective strain, effective stress, total velocity and load-stroke curves etc.

3.5.1 Stress, Strain,Velocity and Flow pattern Analysis

Finite element analysis is carried out for product Collet chuck holder at different punch movements. The following characteristics are analyzed: Strain effective, Stress effective, velocity and metal flow pattern.

3.5.1.1 Collet chuck holder for 18.8 mm length of travel of punch

The simulated shape Collet huck holder is formed for 18.8 mm punch travel. Different characteristics like effective strain, effective stress, total velocity and flow pattern had been shown in the Figures 3.6 and 3.7. From Fig. 3.6 we can observe that the strain is more in the middle portion, extruded part and the interface between the punch and billet portion of the product. The maximum effective strain obtained is 6.06. The effective stress is more in the middle circular portion and extruded part of the product. The maximum effective stress obtained is 135 MPa. From the Fig. 3.7 we can observe that the maximum velocity is on the top portion between punch and billet interface. The maximum velocity obtained is 3.34 mm/sec. The flow pattern diagram shows that the metal flow is concentrated in the center portion of the product.

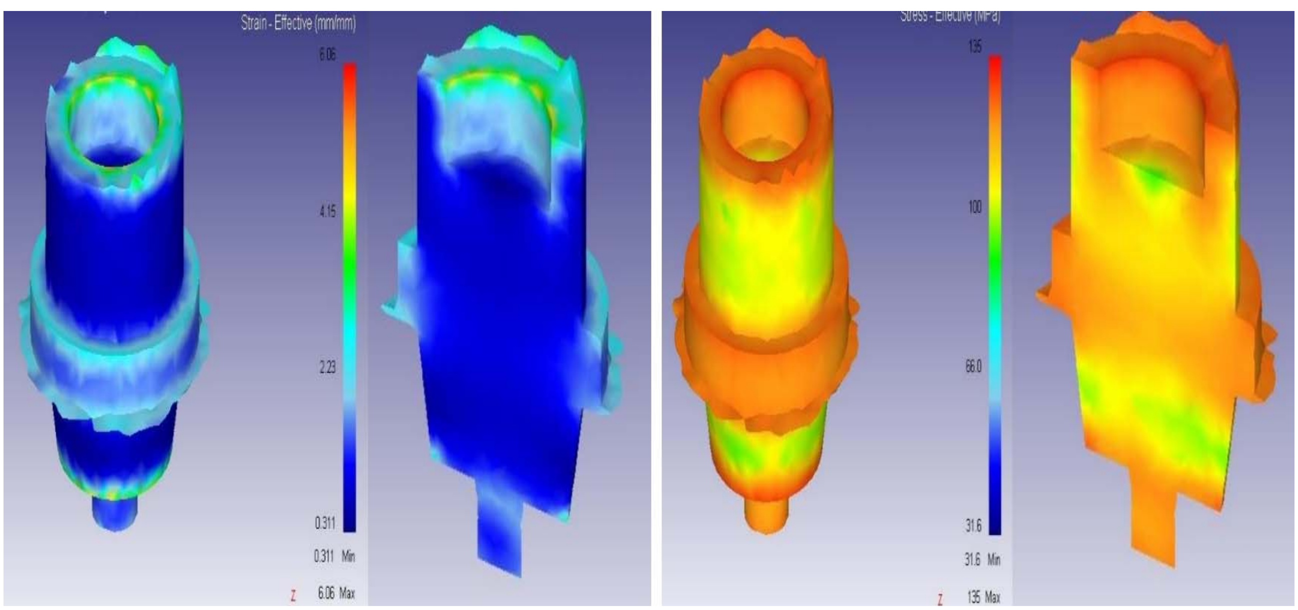


Fig. 3.6: Distribution of Effective strain and Effective stress at 18.8 mm punch movement

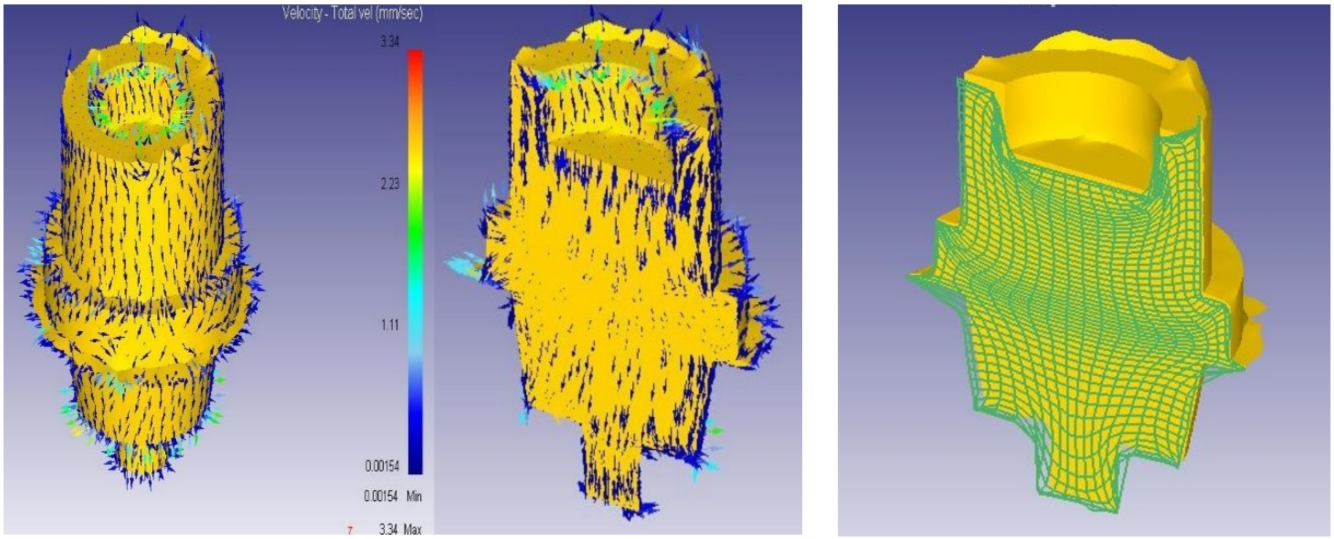


Fig. 3.7: Distribution of velocity and flow pattern at 18.8 mm punch movement

3.5.1.2 Collet chuck holder for 15 mm length of travel of punch

The simulated shape Collet huck holder is formed for 15 mm punch travel. Different characteristics like effective strain, effective stress, total velocity and flow pattern had been shown in the Figures 3.8 and 3.9. From Fig. 3.8 we can observe that the strain is more in the top portion interface between the punch head and a billet portion of the product. The maximum effective strain obtained is 5.46. The effective stress is more in the interface between the punch head and billet top portion of the product. The maximum effective stress obtained is 127 MPa. From the Fig. 3.9, we can observe that the maximum velocity is on the top portion between punch and billet interface. The maximum velocity obtained is 0.361 mm/sec. The flow pattern diagram shows that the metal flow is concentrated in the center portion and the top of the product.

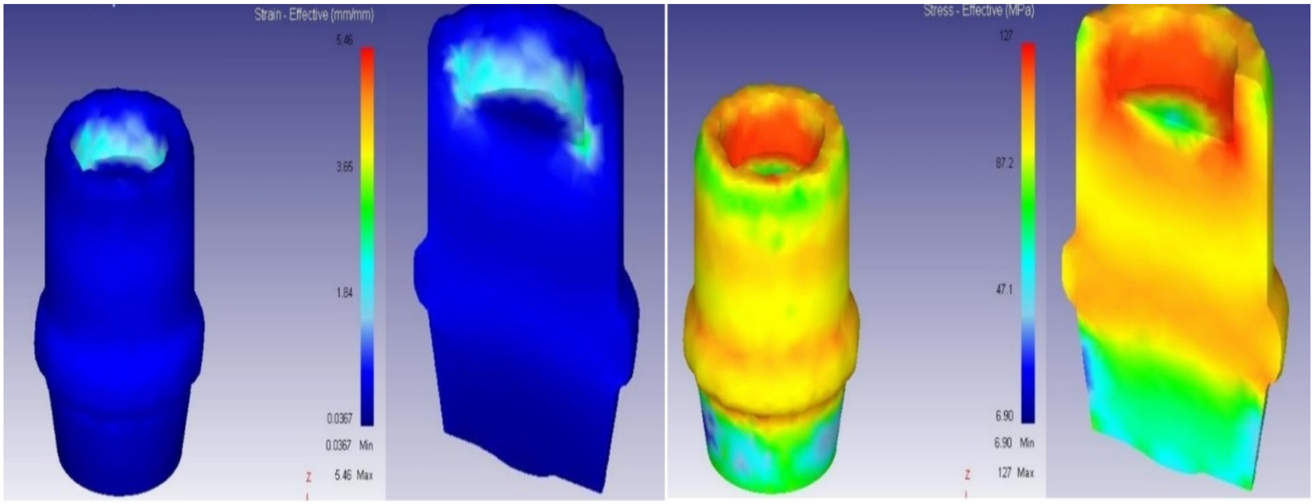


Fig. 3.8: Distribution of Effective strain and Effective stress at 15 mm punch movement

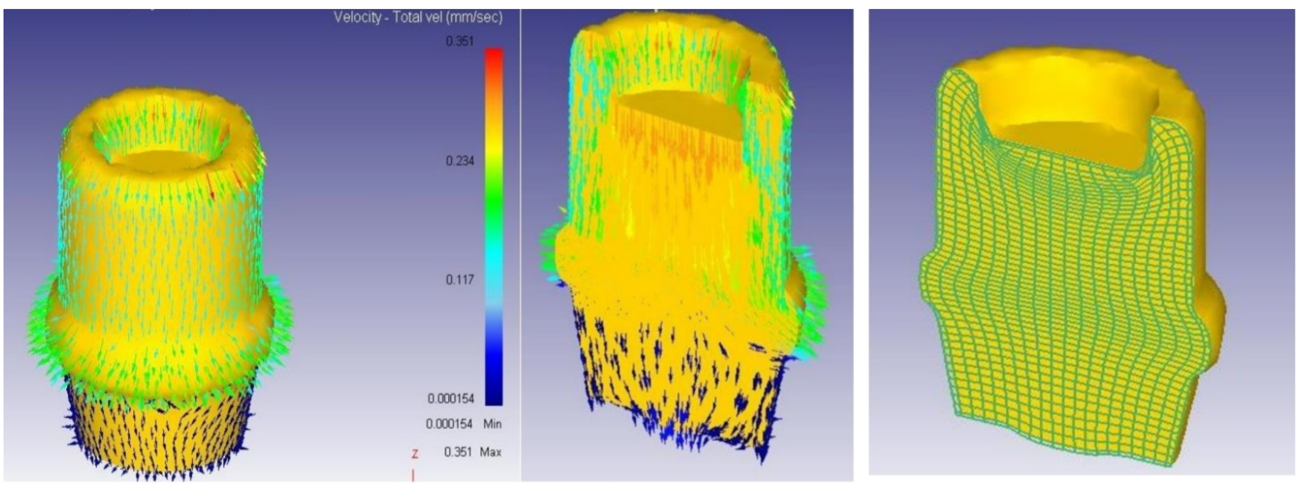


Fig. 3.9: Distribution of velocity and flow pattern at 15 mm punch movement

3.5.1.3 Collet chuck holder for 13 mm length of travel of punch

The simulated shape Collet huck holder is formed for 13 mm punch travel. Different characteristics like effective strain, effective stress, total velocity and flow pattern had been shown in the Figures 3.10 and 3.11. From Fig. 3.10 we can observe that the strain is more in the top portion, interface between the punch head and a billet of the product. The maximum effective strain obtained is 6.55. The effective stress is more in the interface between the punch head and billet top portion of the product. The maximum effective stress obtained is 129 MPa. From the Fig. 3.11 we can observe that the maximum velocity is on the top portion between punch and billet interface. The maximum velocity obtained is 0.341 mm/sec. The flow pattern diagram shows that the metal flow is more in the top portion of the product.

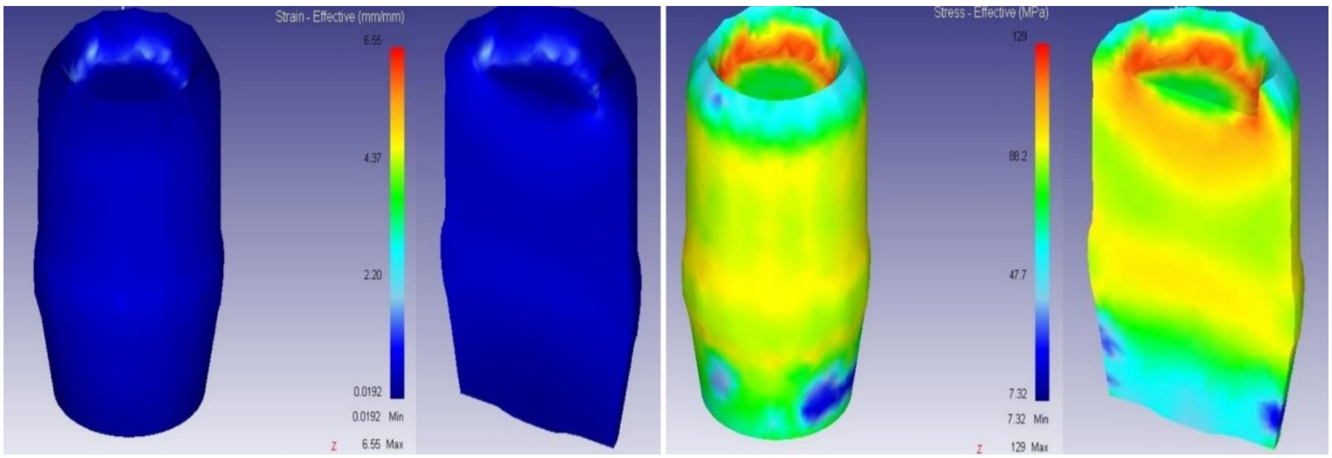


Fig. 3.10: Distribution of effective strain and effective stress at 13 mm punch movement

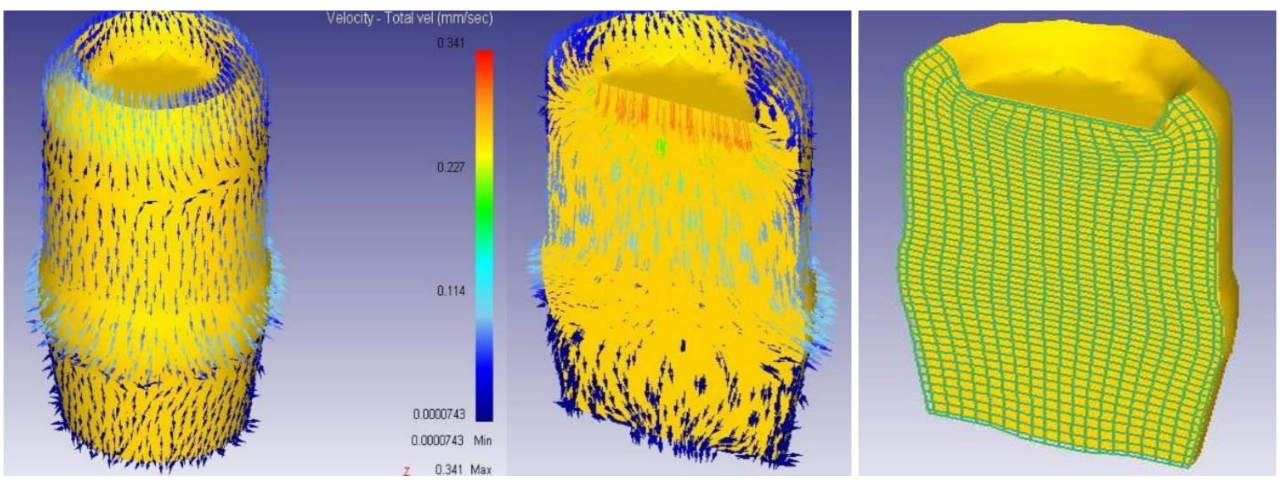


Fig. 3.11: Distribution of velocity and flow pattern at 13 mm punch movement

3.5.1.4 Collet chuck holder for 11 mm length of travel of punch

The simulated shape Collet chuck holder is formed for 11 mm punch travel. Different characteristics like effective strain, effective stress, total velocity and flow pattern had been shown in the Figures 3.12 and 3.13. From Fig. 3.12 we can observe that the strain is more in the top portion, the interface between the punch head and a billet of the product. The maximum effective strain obtained is 1.7. The effective stress is more in the interface between the punch head and billet top portion of the product. The maximum effective stress obtained is 121 MPa. From the Fig. 3.13 we can observe that the maximum velocity is on the top portion between punch and billet interface. The maximum velocity obtained is 0.3 mm/sec. The flow pattern diagram shows that the metal flow is in the initial condition that it is almost equally spread.

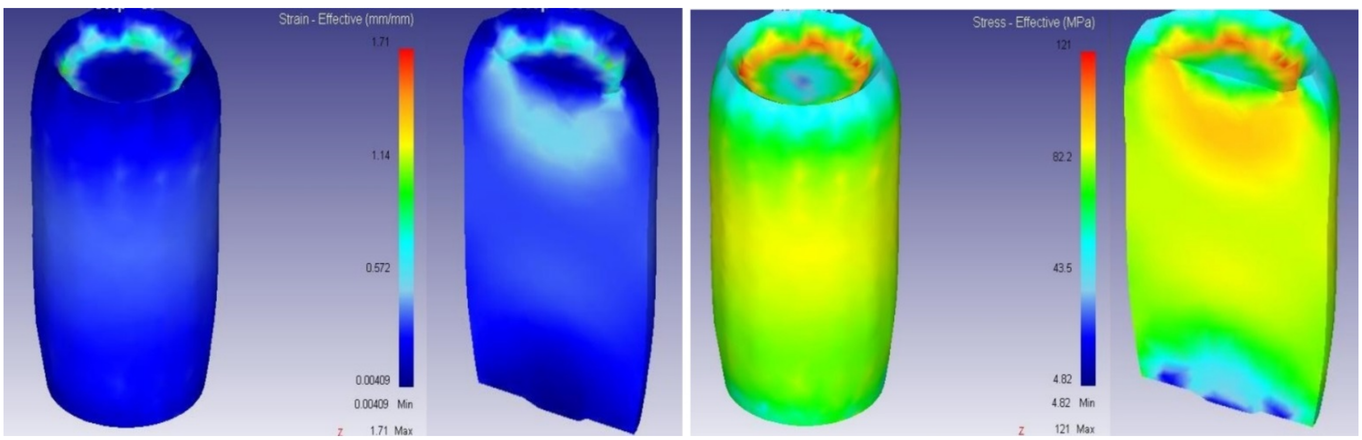


Fig. 3.12: Distribution of effective strain and effective stress at 11 mm punch movement

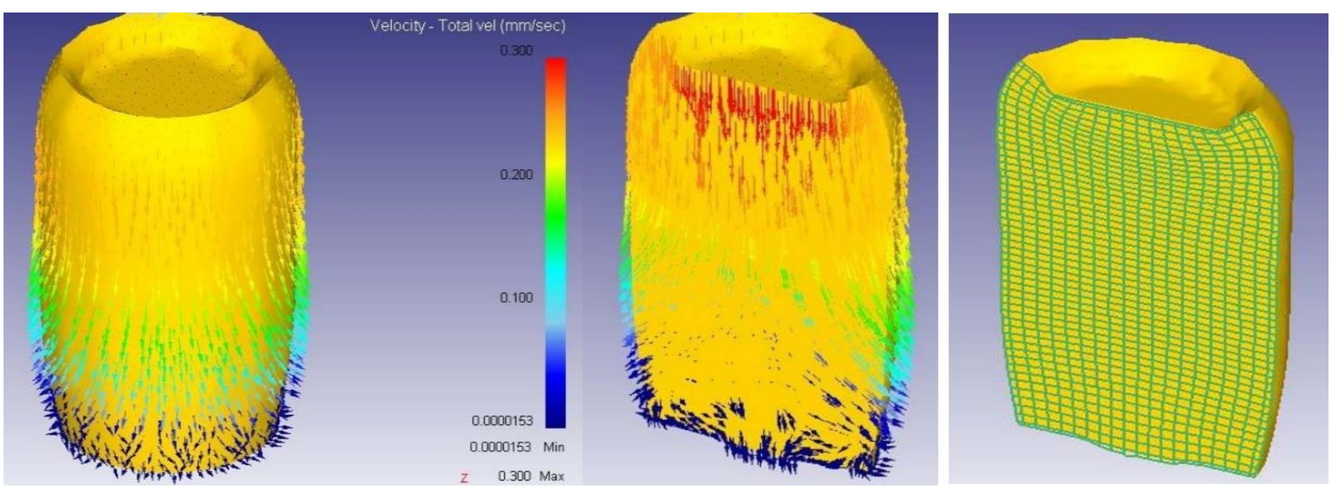


Fig. 3.13: Distribution of velocity and flow pattern at 11 mm punch movement

3.5.2 Variation of load with punch displacement

Figures 3.14-3.17 shows the variation of punch load with punch stroke for different punch movements. For the complete formation of required product 145 KN load is required. The Fig. 3.22 shows the complete product formation at 18.8 mm punch travel. Up to 11 mm there is a very less increase in load. In this stage punch head will penetrate into the billet. After 11 mm, we can observe the significant increase in the load because metal will flow into the circular die and tapered dies. We can observe that up to 11 mm the load obtained is 30.4 KN. After that within 4 mm punch travel load is increased from 30.4 KN to 60.8 KN. After 15 mm we can observe the rapid increase in the load because at this stage metal filled up all dies. From 15 mm to 18.8 mm there is an increase in load from 60.8 KN to 145 KN. This is because in this stage only small extrusion part will form and flash also will occur.

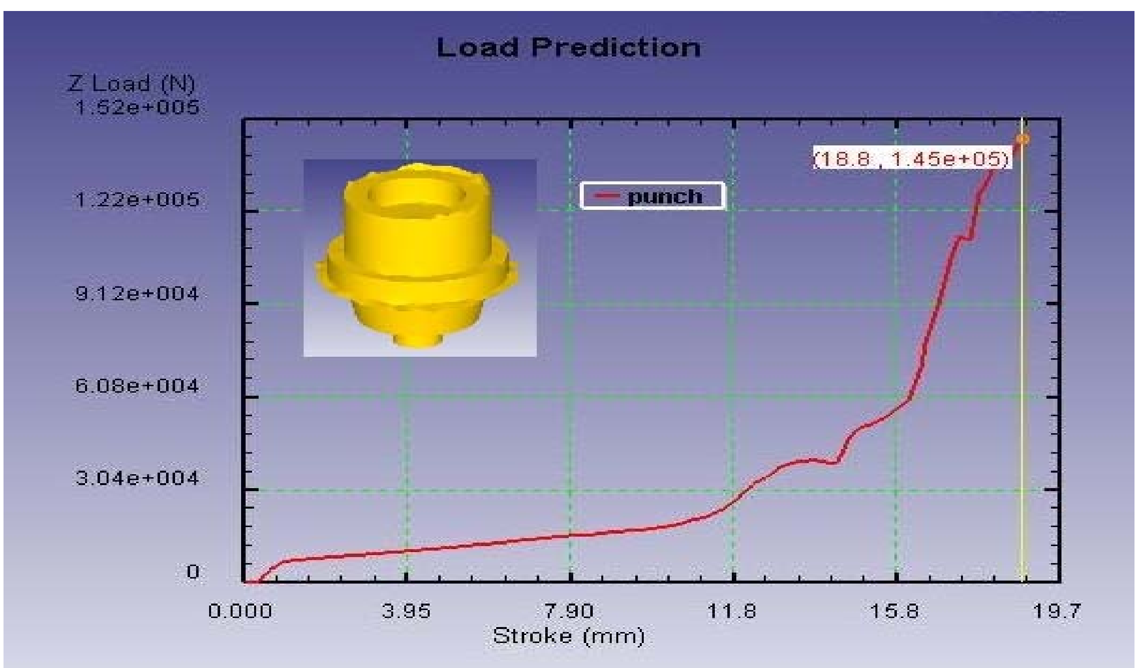


Fig. 3.14: Variation of punch load with stroke for 18.8 mm punch travel

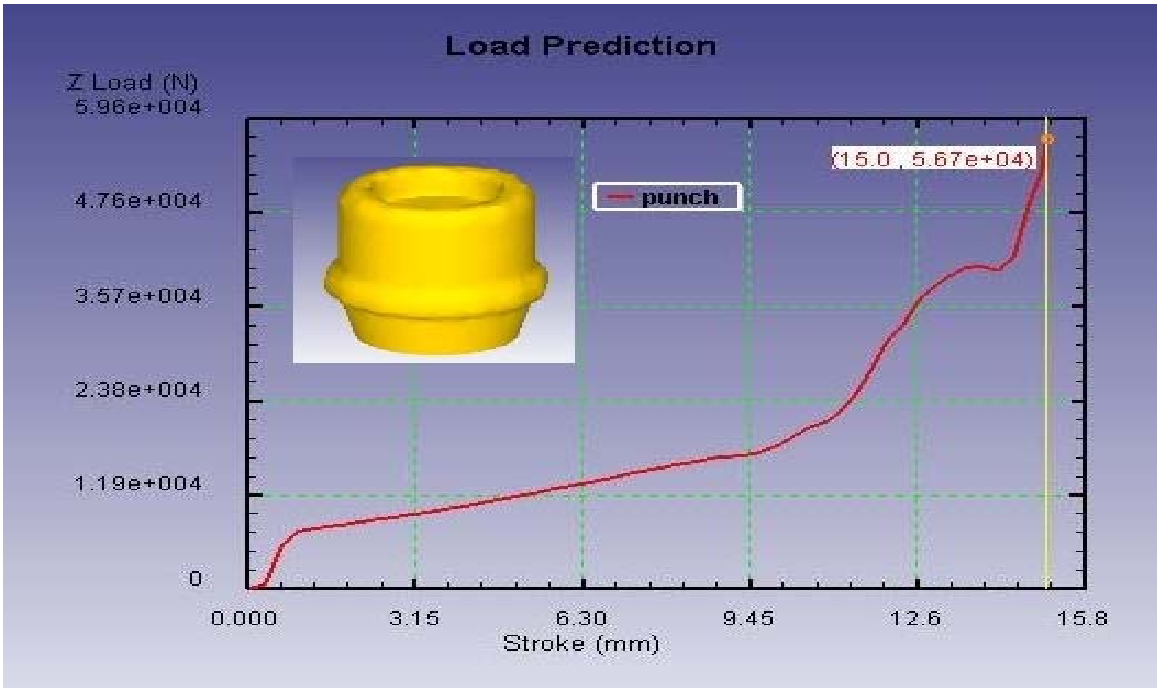


Fig. 3.15: Variation of punch load withy stroke for 15 mm punch travel

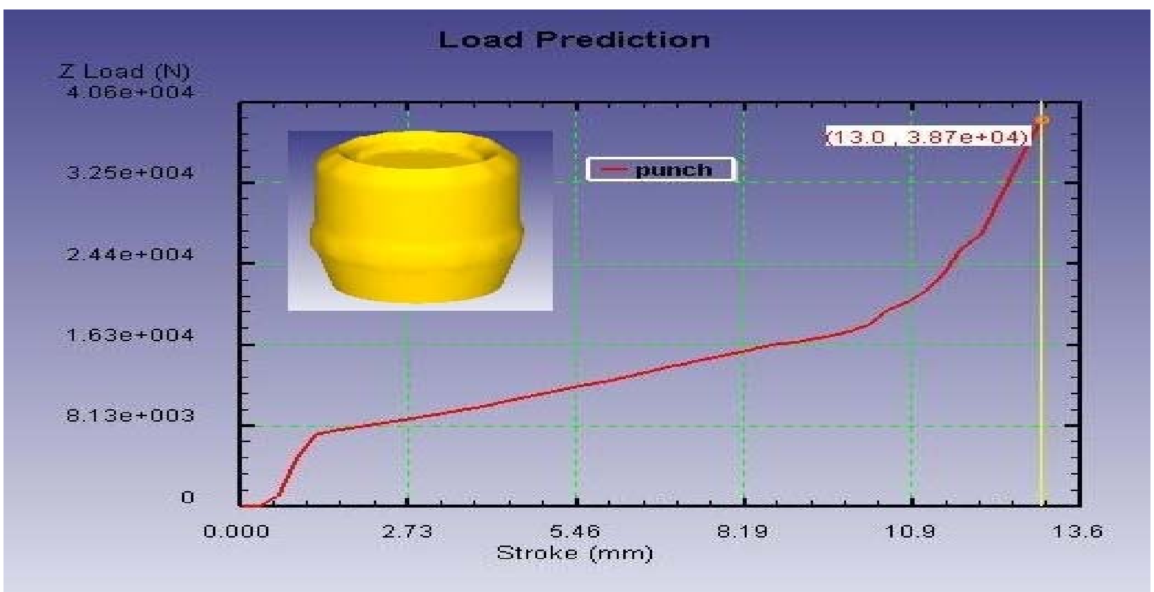


Fig. 3.16: Variation of punch load with stroke for 13 mm punch travel

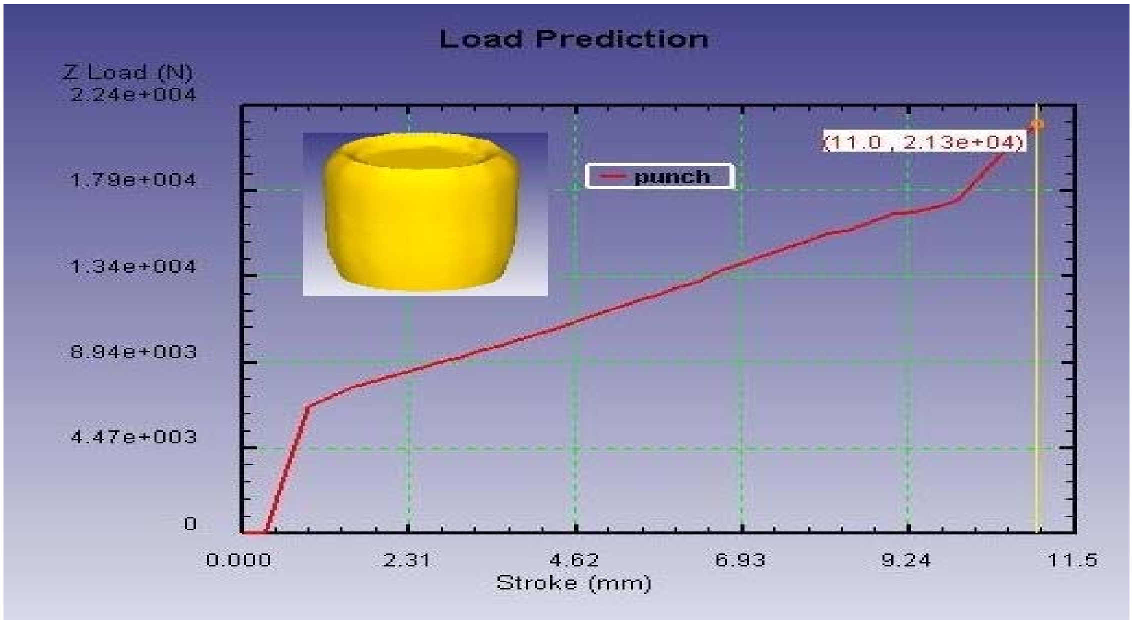


Fig. 3.17: Variation of punch load with stroke for 11 mm punch travel

3.6 Conclusion

Finite element analysis simulation has been successfully implemented for the analysis of Combined extrusion-forging process of the product Collet chuck holder. The simulation process gives visualization of the product before making the experiment. The peak load and punch displacement gives the idea to design the die set up and experimental procedure. Effective strain, Effective stress, Total velocity and Metal flow patterns analysed at different punch movements.

CHAPTER 4

EXPERIMENTAL INVESTIGATION

4.1 Introduction

In the present investigation, experimental studies are carried out with a view to compare the experimental results with the finite element analysis obtained from commercially available FEM software. Experiments are performed on an INSTRON®600KN Universal testing machine (maximum capacity of 600kN) for combined extrusion-forging of aluminum billet using circular dies to form product Collet chuck holder. A setup has been designed and fabricated for making Collet chuck holder using combined extrusion-forging process.

4.2 The Test rig

The apparatus mainly consists of these parts; the punch rod, the punch head, the container, the container sleeve, the forging-extrusion die holders, Base plate, and a series of forging-extrusion dies with different shape. The different components used in the experimental setup are shown in the Table. The container (140mmφ diameter and 100mm length) is made of EN31 steel, and having a cylindrical chamber (50mmφ and 100mm length). This is accomplished first by turning the outer diameter and drilling the inner chamber (having tolerance of ± .02mm) using wire cut EDM. The Fig. 4.2 shows the container. A cover plate is used to avoid the back slip of the container sleeve during experimentation. The Fig. 4.3 shows the container cover plate. A container sleeve which is inserted into the container, whose outer diameter matches with inner diameter of the container and inner diameter matches with outer diameter of main punch. The function of the container sleeve is to guide the punch rod through the container and avoid bulging of punch rod. The Fig. 4.4 shows the container sleeve. Similar processes are followed for manufacturing of the extrusion-forging die holder. Figures 4.5 and 4.7 shows the die holder -1 and die holder -2. Punch rod and circular punch head are made of D2 steel which are shown in the Figures 4.12 and 4.13. The punch head is attached to the punch rod-2 by using a push fit arrangement. Base plate and support plate are made of EN 8 steel. The base plate is shown in the Fig. 4.14. Tis base plate will be fixed at the end f two die holders for supporting purpose. Figures 4.8-4.11 illustrate the circular split dies, circular taper split die respectively with detail drawings.

Table 4.1: List of components for combined extrusion-forging processs

SL. NO.	DESCRIPTION	QTY.	MATERIAL	SIZE	REMARK
1.	COVER PLATE	1	EN8	Ø140×10	HRc 45-48
2.	CONTAINER	1	EN31	Ø140×100	HRc 45-48
3.	CONTAINER SLEEVE	1	EN31	Ø50×100	HRc 45-48
4.	DIE HOLDER -1	1	EN31	Ø140×50	HRc 45-48
5.	DIE HOLDER -2	1	EN31	Ø140×20	HRc 45-48
6.	SUPPORT PLATE	1	EN8	Ø160×20	HRc 45-48
7.	PUNCH ROD-1	1	D2	Ø30×150	HRc 50-55
8.	PUNCH ROD-2	1	D2	Ø18×55	HRc 50-55
9.	CIRCULAR PUNCH HEAD	1	D2	Ø 12×5	HRc 50-55
10.	CIRCULAR SPLIT DIE -1	01 Set	D2	Ø 6×5	HRc 50-55
11.	TAPERED CIRCULAR SPLIT DIE	01 Set	D2	Ø 18×8	HRc 50-55
12.	CIRCULAR SPLIT DIE WITH FLASH	01 Set	D2	Ø22×5	HRc 50-55
13.	CIRCULAR SPLIT DIE -2	01 Set	D2	Ø18×52	HRc 50-55
14.	BASE PLATE	1	EN8	Ø140×30	HRc 45-48
15.	PUNCH PLATE	1	EN31	Ø160×20	HRc 45-48
16.	COUNTER SHINK SCREW	4	EN31	M8×15	
17.	ALLEN SCREW	1	EN31	M8×30	
18.	ALLEN SCREW	4	EN31	M10×110	

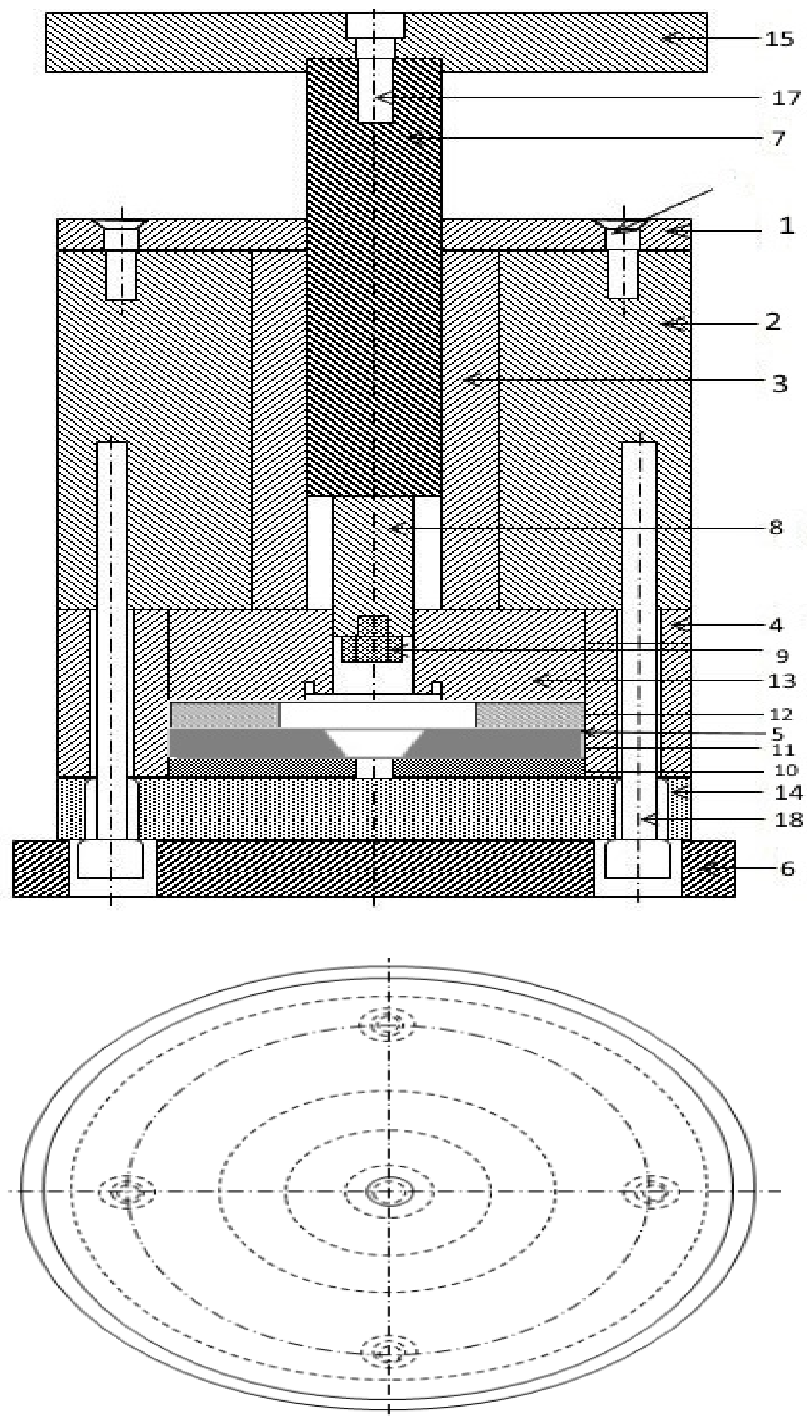


Fig. 4.1: Extrusion-Forging die setup assembly

Name of different components are as follows; 1-Cover Plate, 2-Container, 3-Container Sleeve, 4-Die holder-1, 5-Die holder-2, 6-Support Plate, 7-Punch rod-1, 8-Punch rod-2, 9-Circular Punch head, 10-Circular split die -1, 11-Tapered Circular split die, 12-Circular split die with flash, 13-Circular split die-2, 14-Base plate, 15-Punch plate, 16-Counter shrink screw, and 17&18-Allen screw

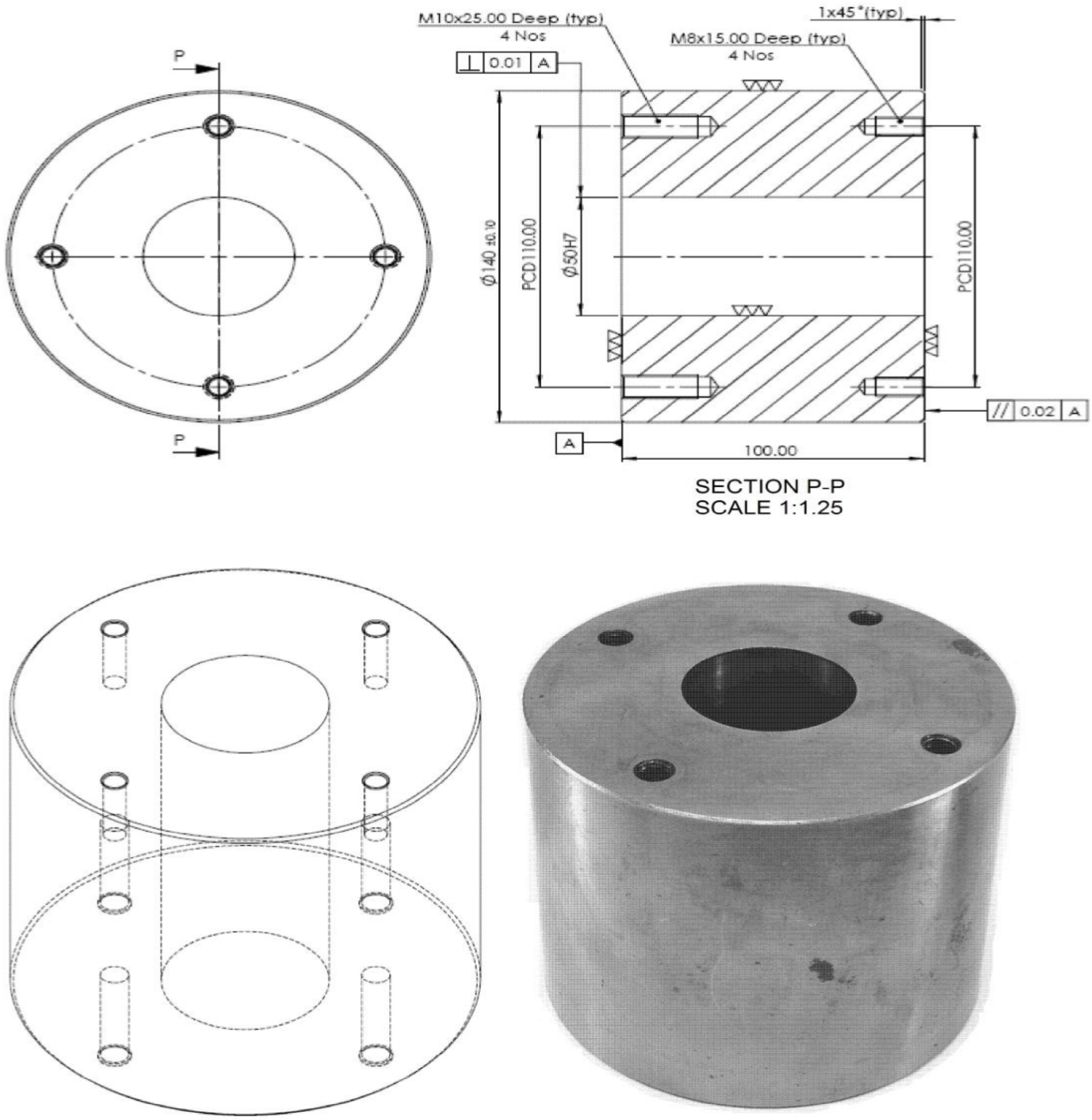


Fig. 4.2: Container [23]

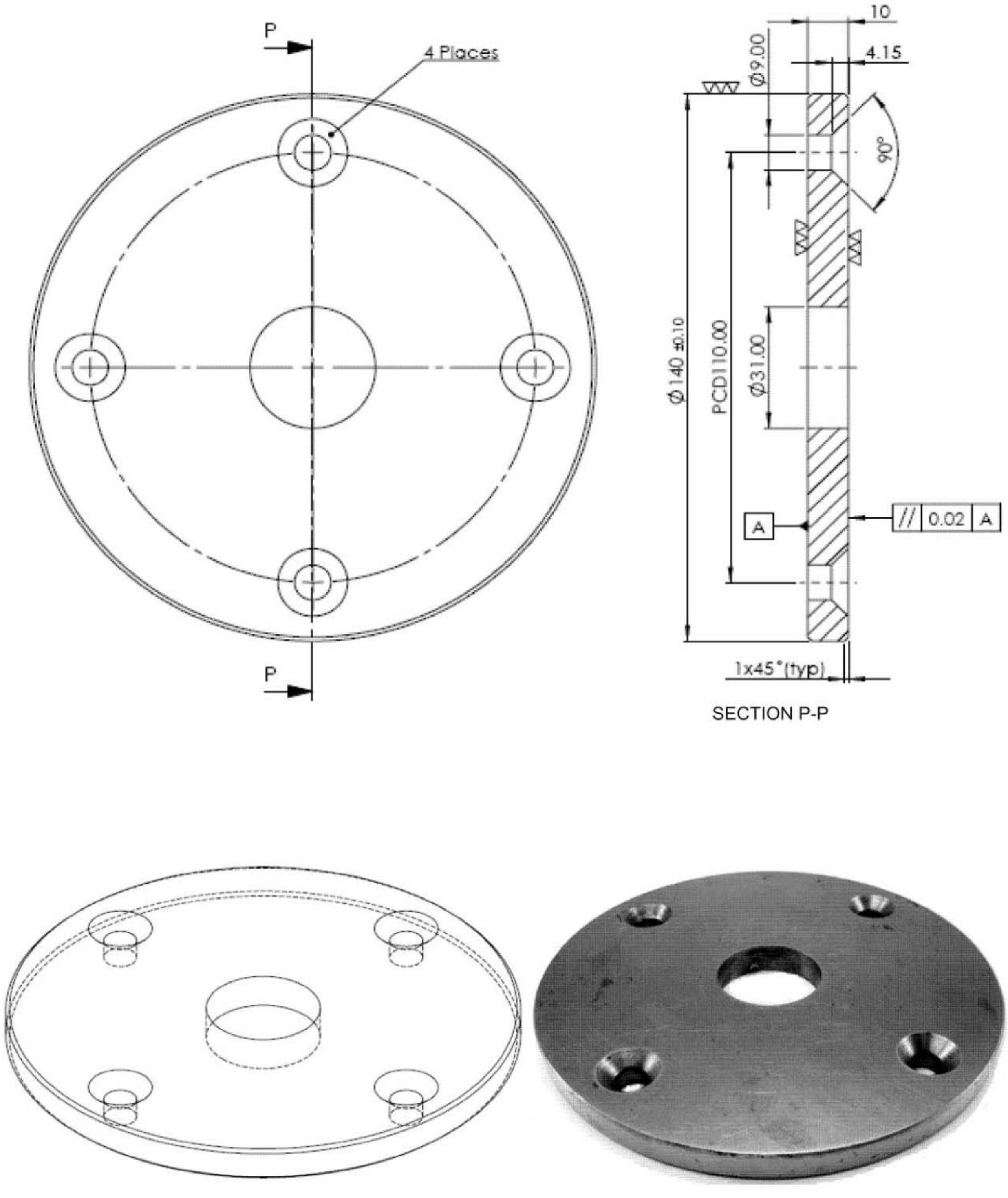


Fig. 4.3: Cover plate for container [23]

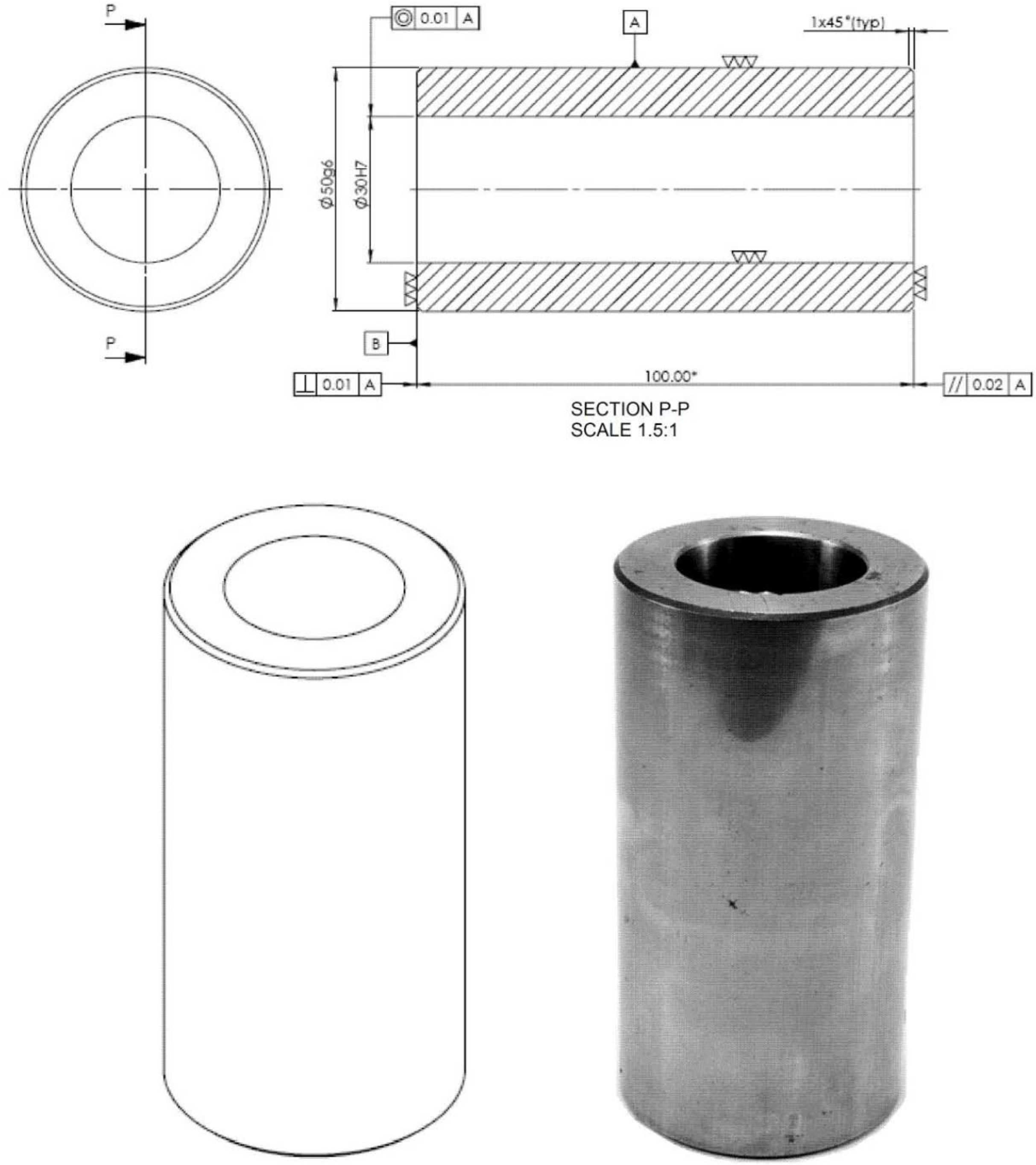


Fig. 4.4: Container sleeve [23]

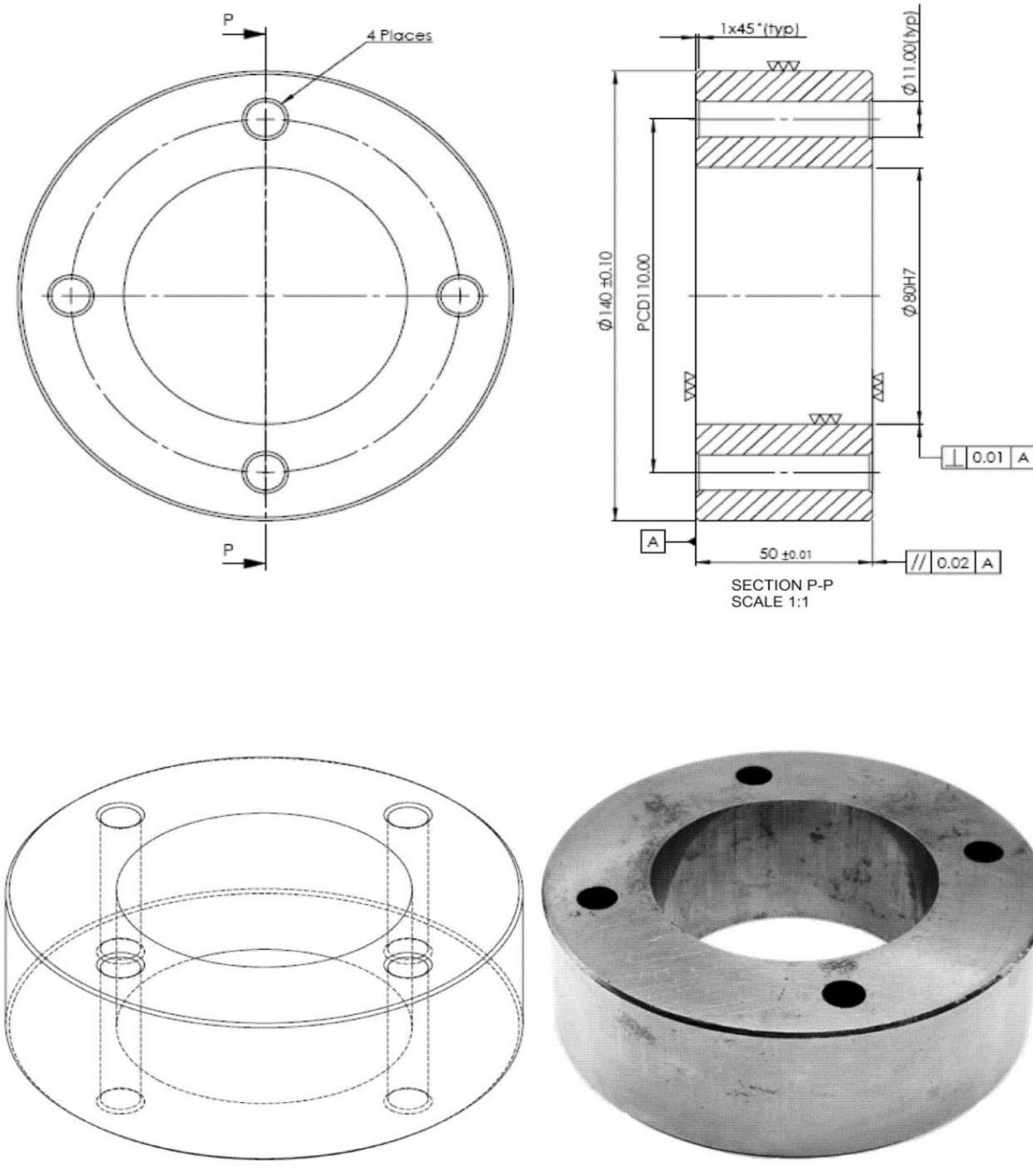


Fig. 4.5: Die holder-1 [23]

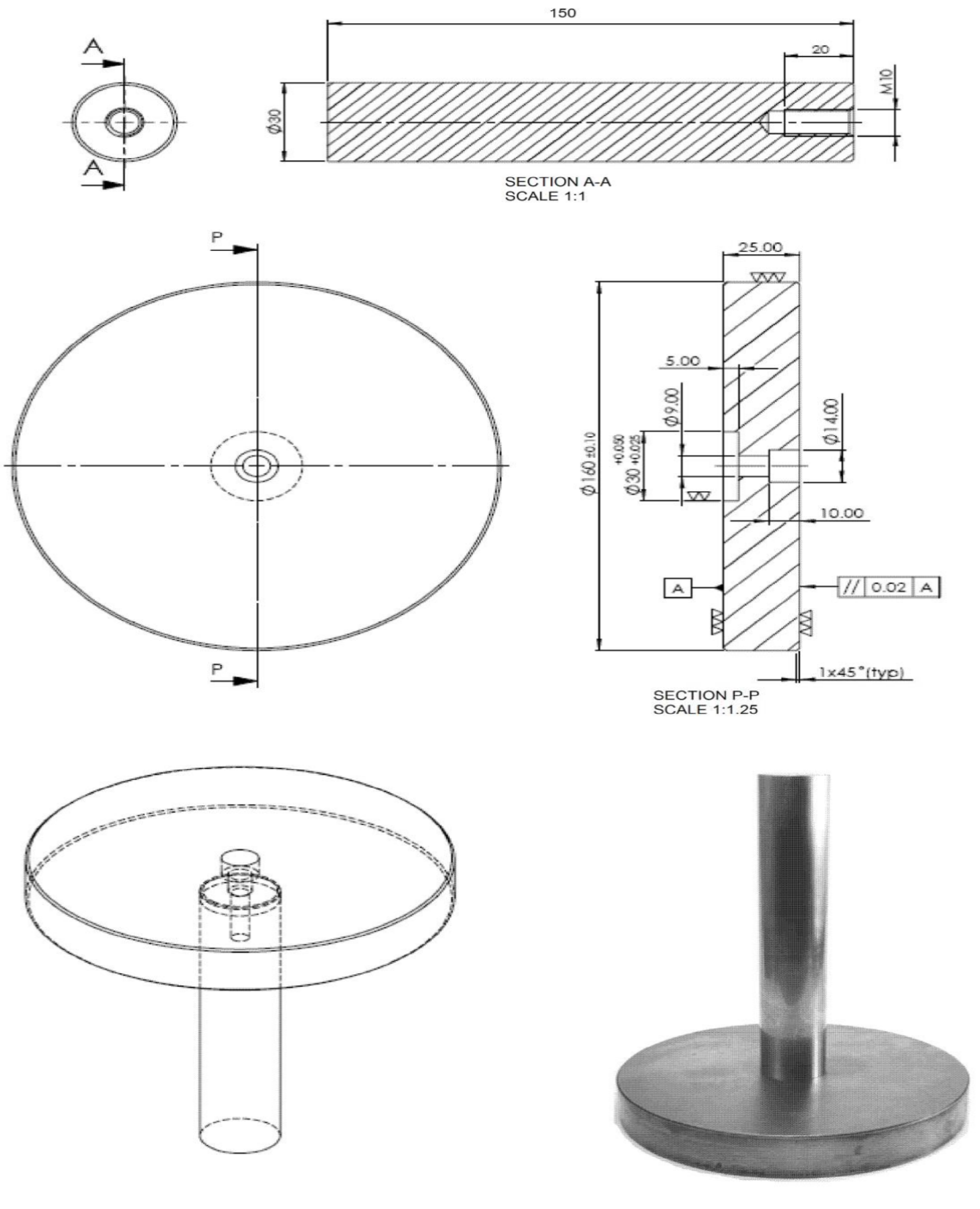


Fig. 4.6: Punch with punch plate [23]

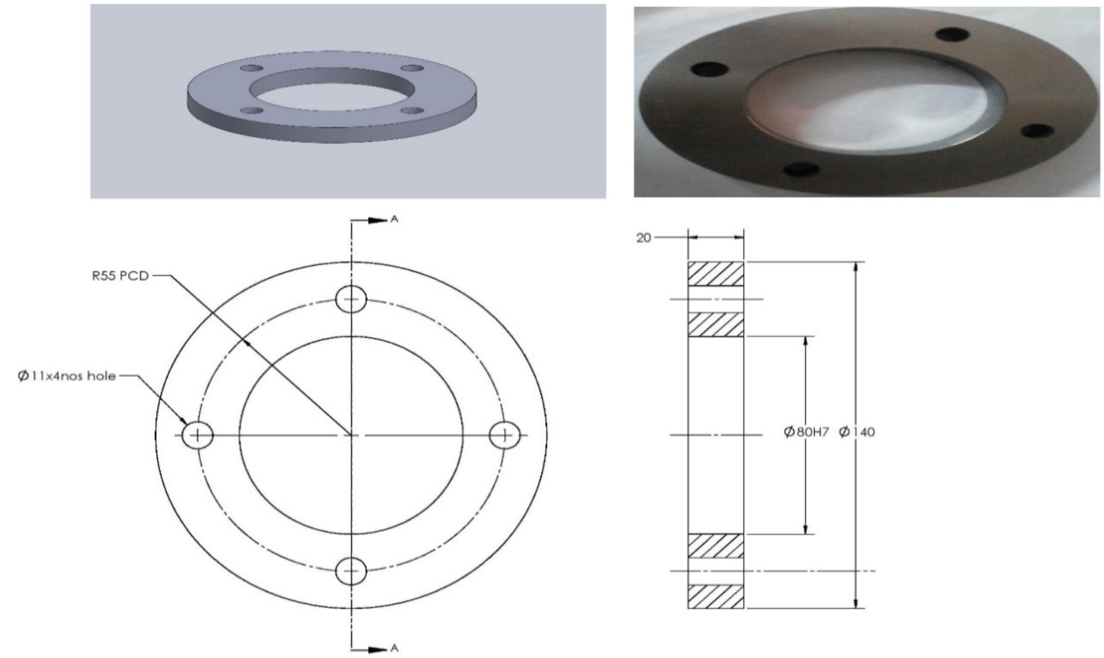


Fig. 4.7: Die holder-2

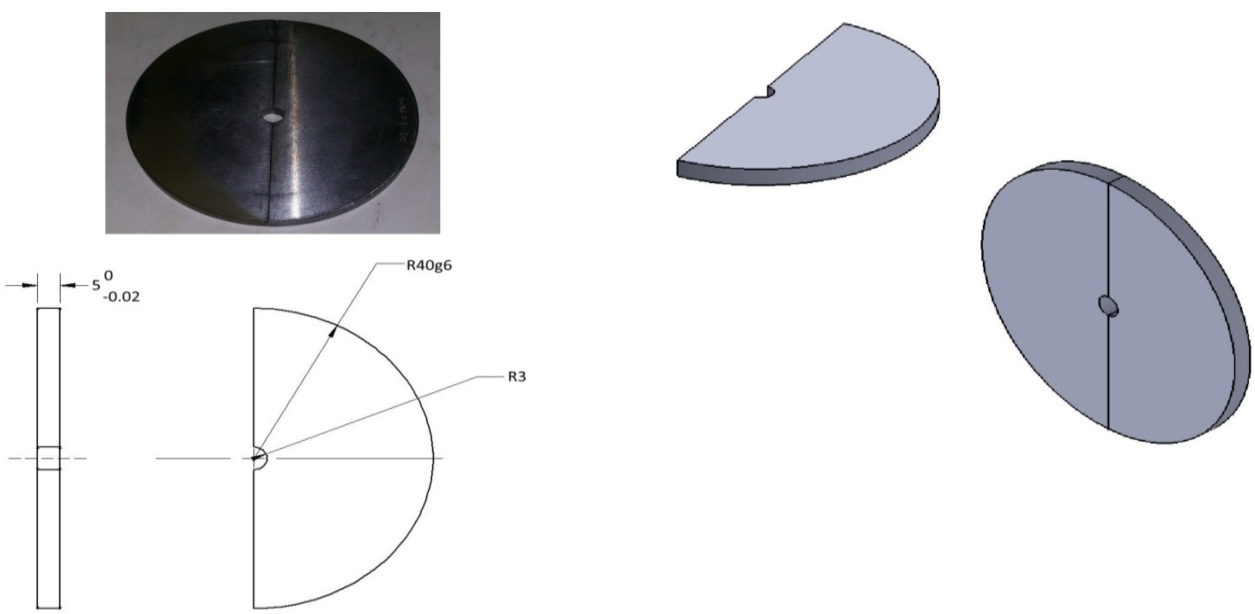


Fig. 4.8: Circular split die -1

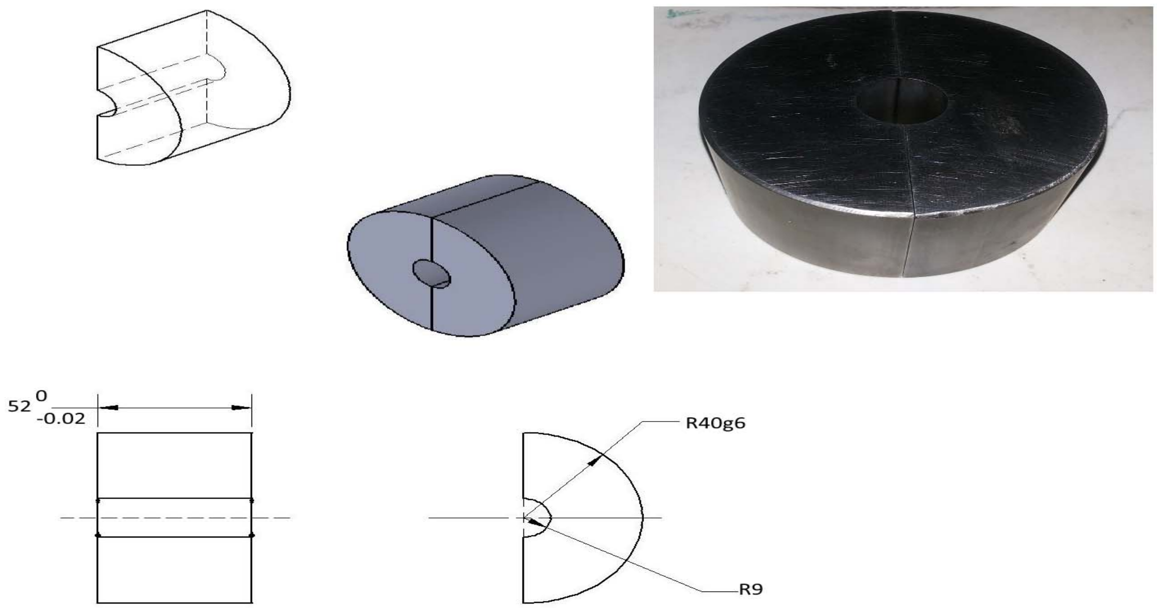


Fig. 4.9: Circular split die -2

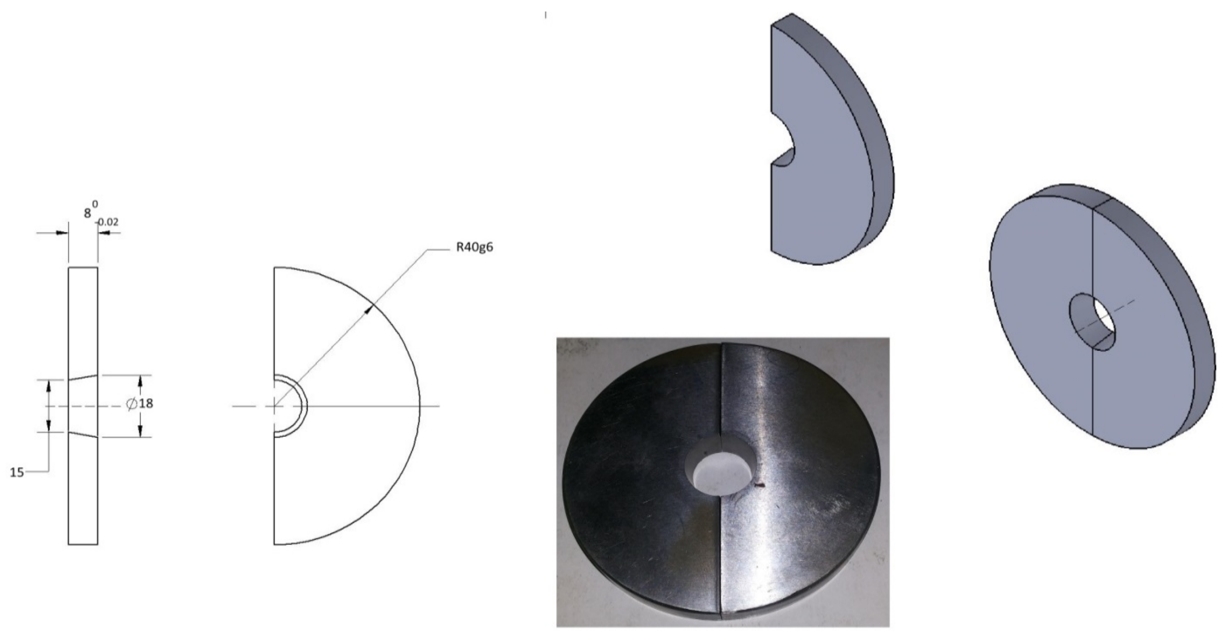


Fig. 4.10: Tapered circular split die

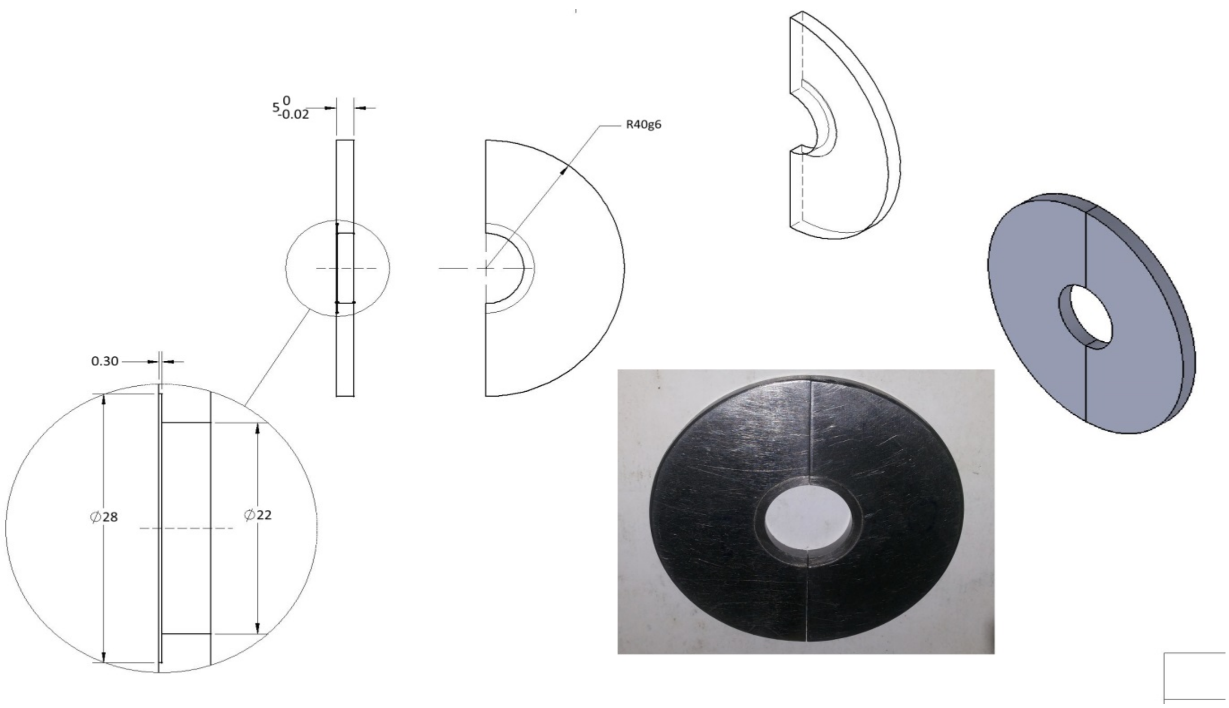


Fig. 4.11: Circular split die with flash

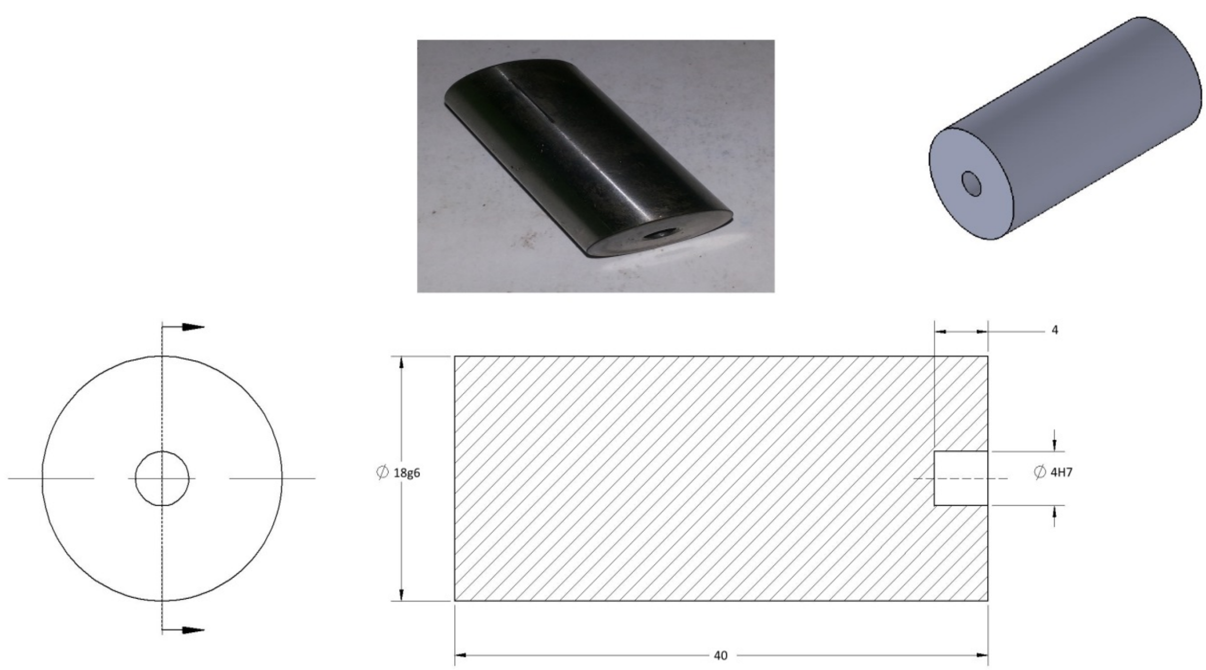


Fig. 4.12: Punch rod -2

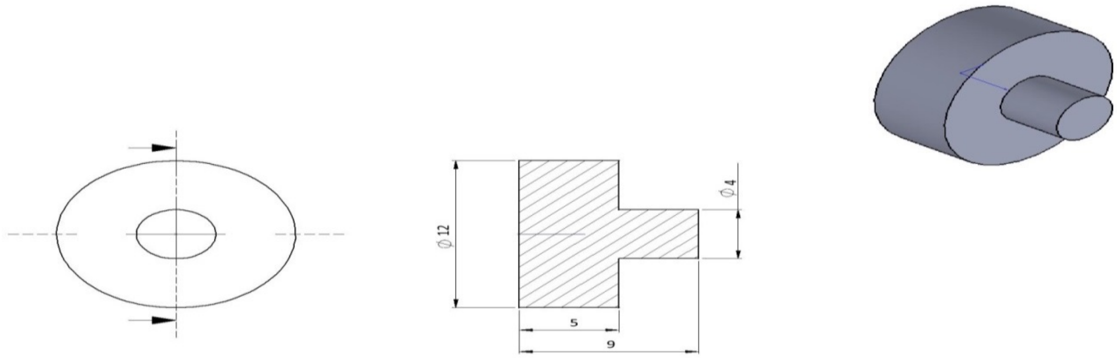


Fig. 4.13: Punch head

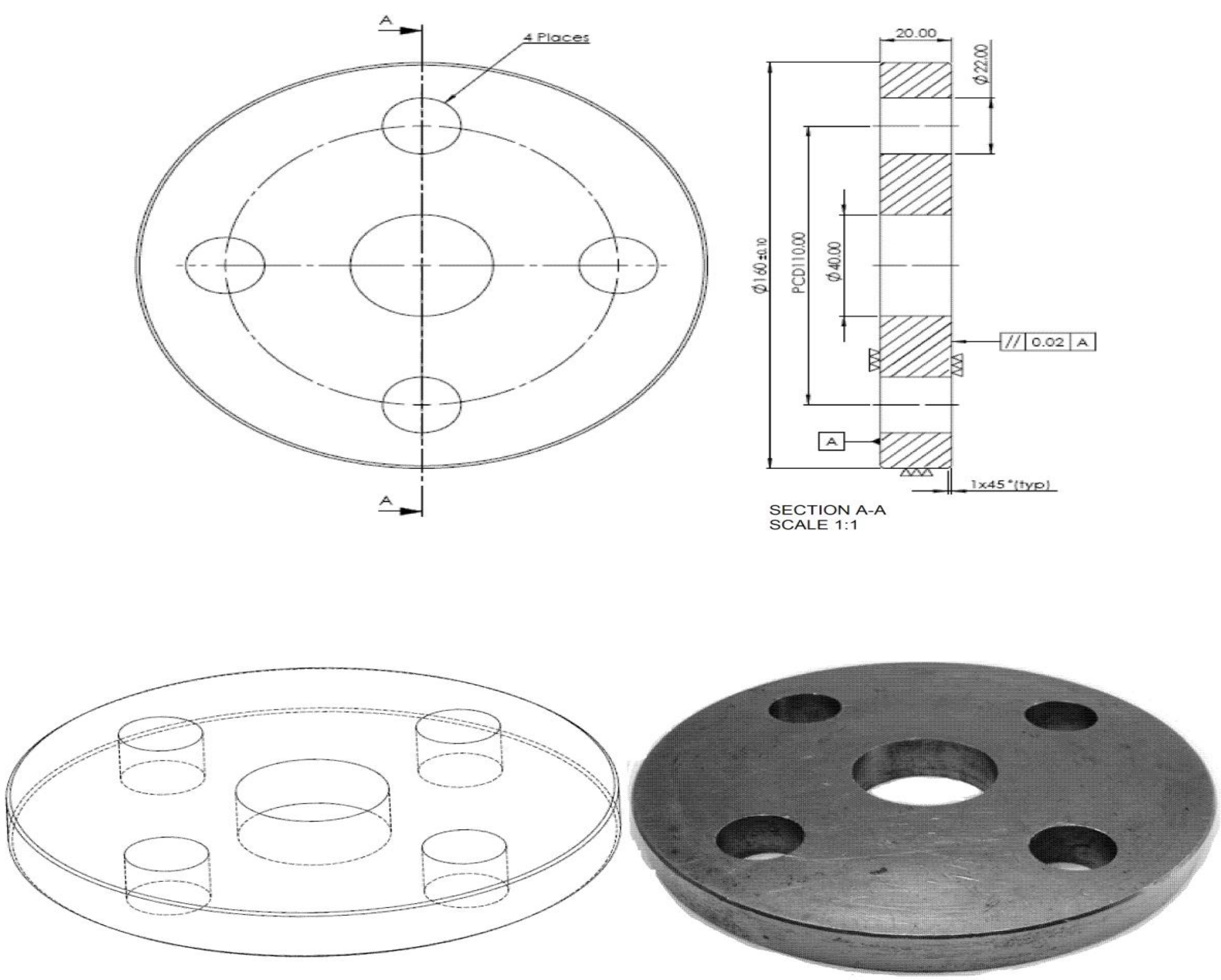


Fig. 4.14: Base plate [23]

4.3 Experimental setup and Procedure

In present experiment aluminum is taken as billet material and experiments are performed on the INSTRON – 600 KN Universal testing machine. The die sets, punch, die holders and container sleeve should be cleaned for removing the already used grease. After that again grease should be applied to the inner surfaces of he die surfaces, punch and sleeve for lubrication purpose. Aluminum billet is also lubricated and placed inside the cavity of the die sets. After that punch is placed on the billet. After that, container placed on the die holder which is fixed by using the bolts. This entire setup is placed on the lower table of the universal testing machine (INSTRON – 600 KN) and load will be applied by using an upper table. After this setup, the machine is switched on and the parameters have been set. The punch movement is taken as 1 mm/min. To avoid rate affect, the movement of the punch being adjusted to 1 mm per minute. Punch load is recorded at every 30sec of punch travel. Stopping criteria of the machine is given as punch movement or length of travel of punch. After the machine had travelled the specified punch movement the machine will stop. After experimentation is completed, punch and container are removed from the assembly. The two die holders are separated from the base plate. The die sets with the product are pressed from the die holders. Then the required product Collet chuck holder is obtained from the split die halves. Experiments were conducted for Collet chuck holders with various punch movements. The experiments are conducted to find out the metal flow pattern at different punch movements.

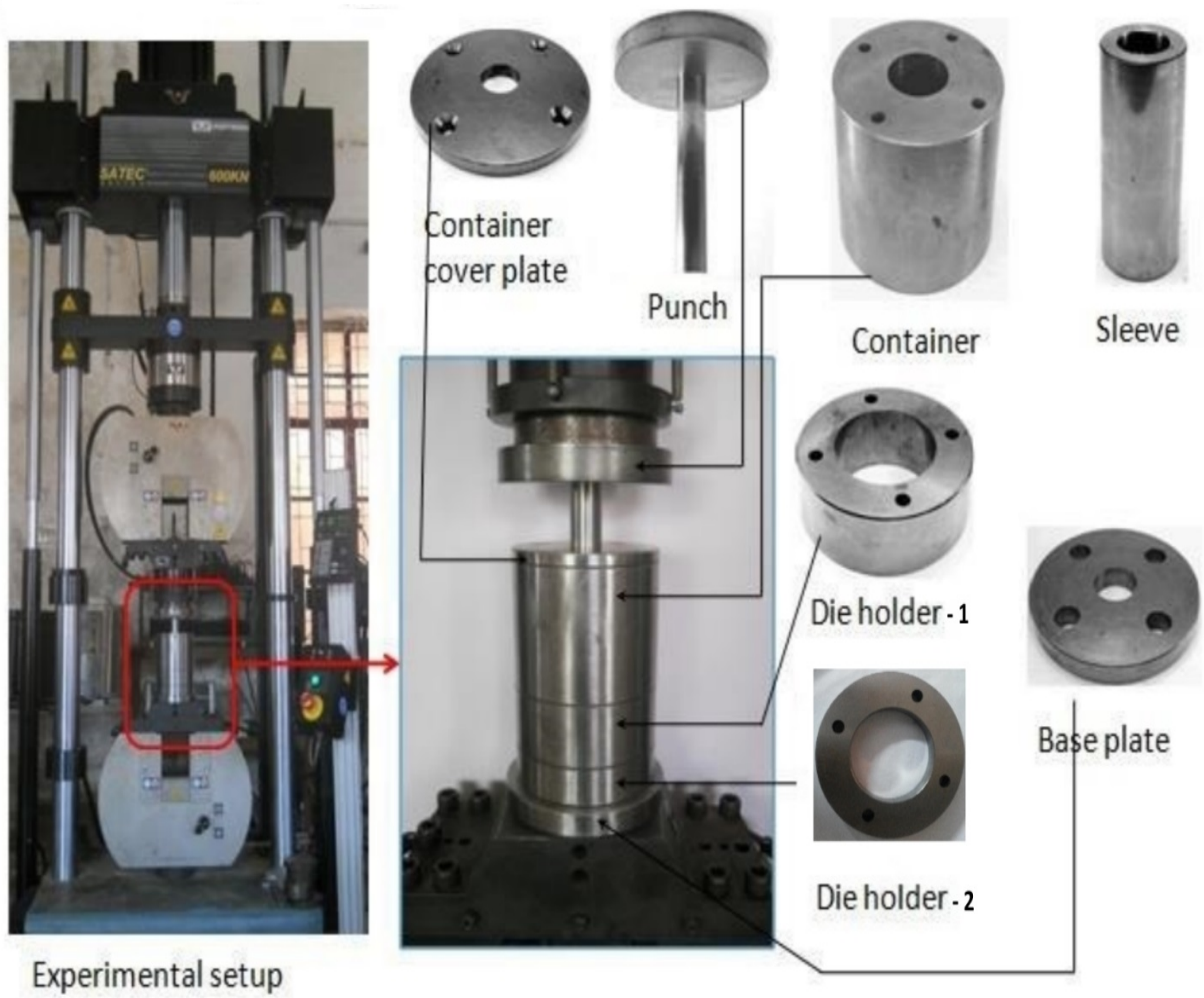


Fig. 4.15: Photographic view of experimental setup with main components

4.4 Determination of stress-strain characteristic of aluminum

To determine the flow stress of the aluminum specimen, we have to conduct an experiment on stress-strain characteristics. The experimental setup for determining stress-strain characteristics has been shown in the Fig. 4.16. In order to plot the stress-strain characteristics, a cylindrical specimen with 24mm diameter and 40 mm length has been machined form casted billet material. Some oil grooves are made on both the ends of the specimen to entrap the lubricant. The ends were adequately lubricated with grease and it is tested on the uniaxial compression INSTRON®-600KN hydraulic pressing machine. The compressive load is recorded for every 0.5 mm of punch travel. After it is compressed for 5 mm it is taken out from the sub-press and re-machined to the cylindrical shape of diameter 24mm with oil groves turned on it again to entrap lubricant. After that it is again compressed to 5mm and this process continues till the height becomes 23.5 mm. The stress strain diagram for aluminum is shown in the Fig. 4.17.

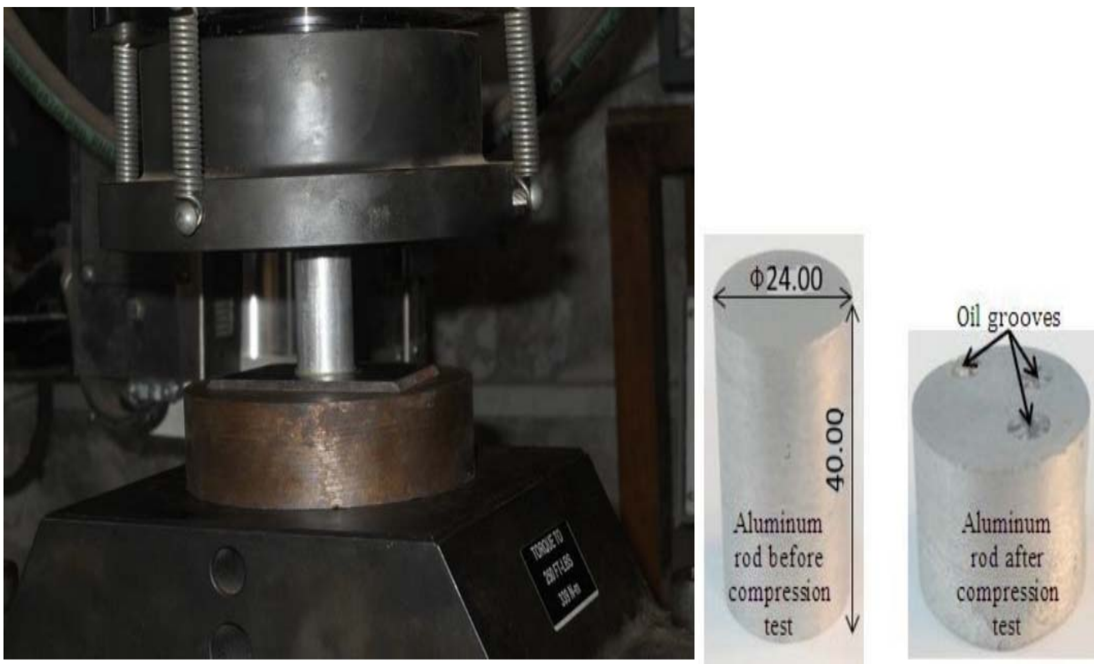


Fig. 4.16: Compression test setup with aluminum specimen

From the above graph we can determine a fitting curve of power equation with strength coefficient (k) 280 MPa and strain hardening exponent (n) 0.495 as shown in the equation below

$$\sigma = 280 * \varepsilon^{0.495}$$

The flow stress obtained from stress-strain curve is 132 MPa and the power equation is used in the simulation process.

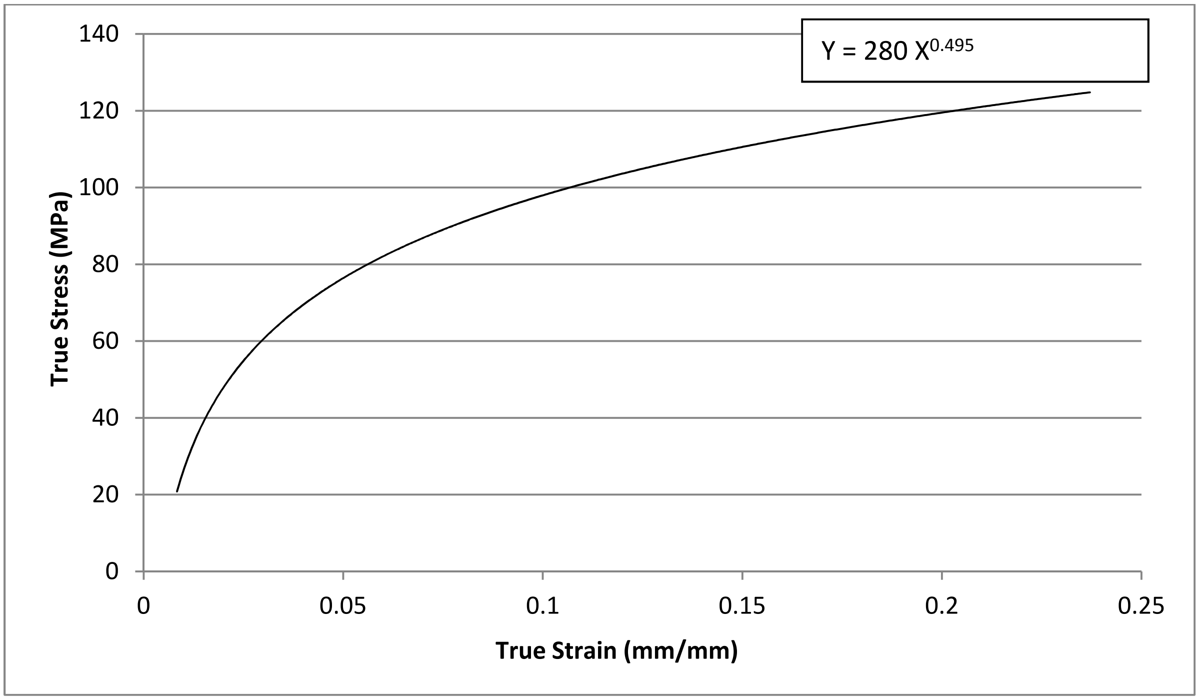


Fig. 4.17: Stress-Strain (Flow stress) curve for Aluminum specimen

4.5 Determination of Friction factor using Ring test

Frictional conditions at the interface between material/die is a significant factor which influences the forming load, metal flow pattern and internal grain structure of the product in metal forming processes. When a flat ring specimen is compressed plastically between two flat platens, increasing friction means poor lubrication results in an inward flow of the metal while decreasing friction means good lubrication results in an outward flow of the metal. So in compression test, if the internal diameter increases, it represents low friction and if the internal diameter decreases it represents high friction. The Fig. 4.18 shows the change in shape of the specimen when it is compressed with lubrication and without lubrication.

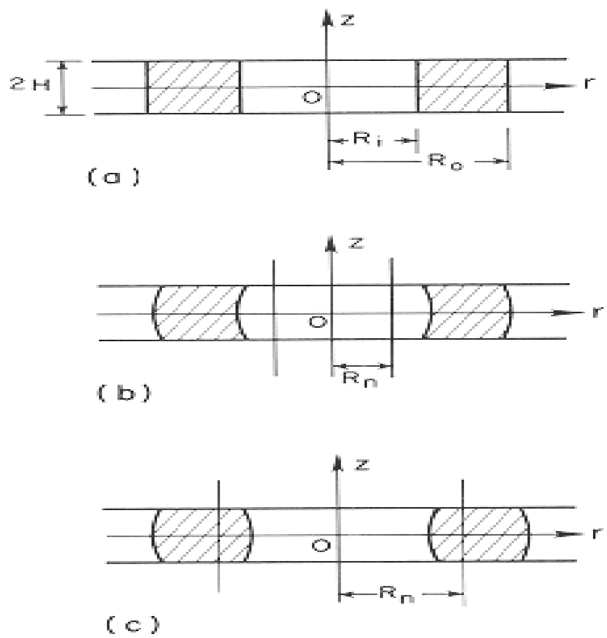


Fig. 4.18: (a) specimen before ring test, (b) Specimen after ring test with lubrication, (c) Specimen after ring test without lubrication [20]

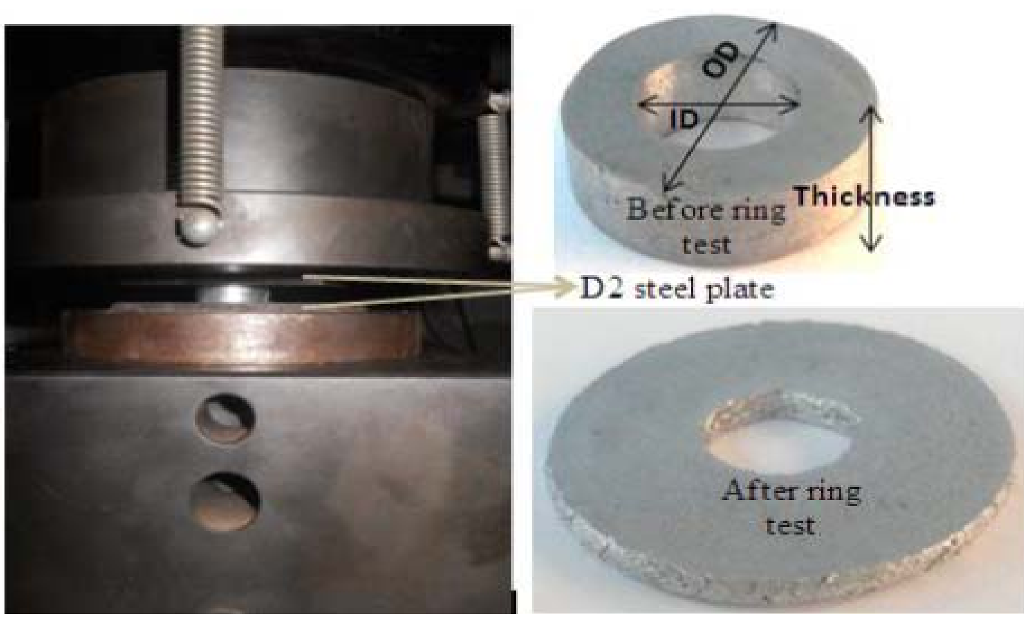


Fig. 4.19: Setup for ring test

In our experimentation, experiments are carried out for both with lubrication and without lubrication conditions. As shown in Fig. 4.19, a flat ring shaped specimens having OD : ID : Thickness ratio 6:3:2 is considered for ring test. The dimensions of the ring used for both with lubrication and without lubrication conditions are 25 : 12.5 : 8.3. To estimate the accurate friction between the die inner surface and billet material, two flat die plates with same internal surface conditions are used for compression. In this test, the ring type of specimen with required dimensions has been compressed as shown in the Fig. 4.19. For every 1 mm compression, we had taken values of outer diameter, internal diameter and thickness. The experiment was continued until the the ring specimen acquires the least dimensions. After the ring test has been completed, the graph had been drawn with the obtained values from experiment. The curve obtained by the values form ring test is compared with standard calibration curves. From this we can obtain the friction factor values. The friction factor obtained for ring test with lubrication is 0.19 and for without lubrication is 0.38. In Finite element analysis we use this friction factor as one input parameter for simulation analysis. The friction factor value with lubrication is taken as reference value while doing FEM analysis simulation. The below Figures 4.20 and 4.21 shows the theoretical calibration curves for ring tests with lubrication and without lubrication.

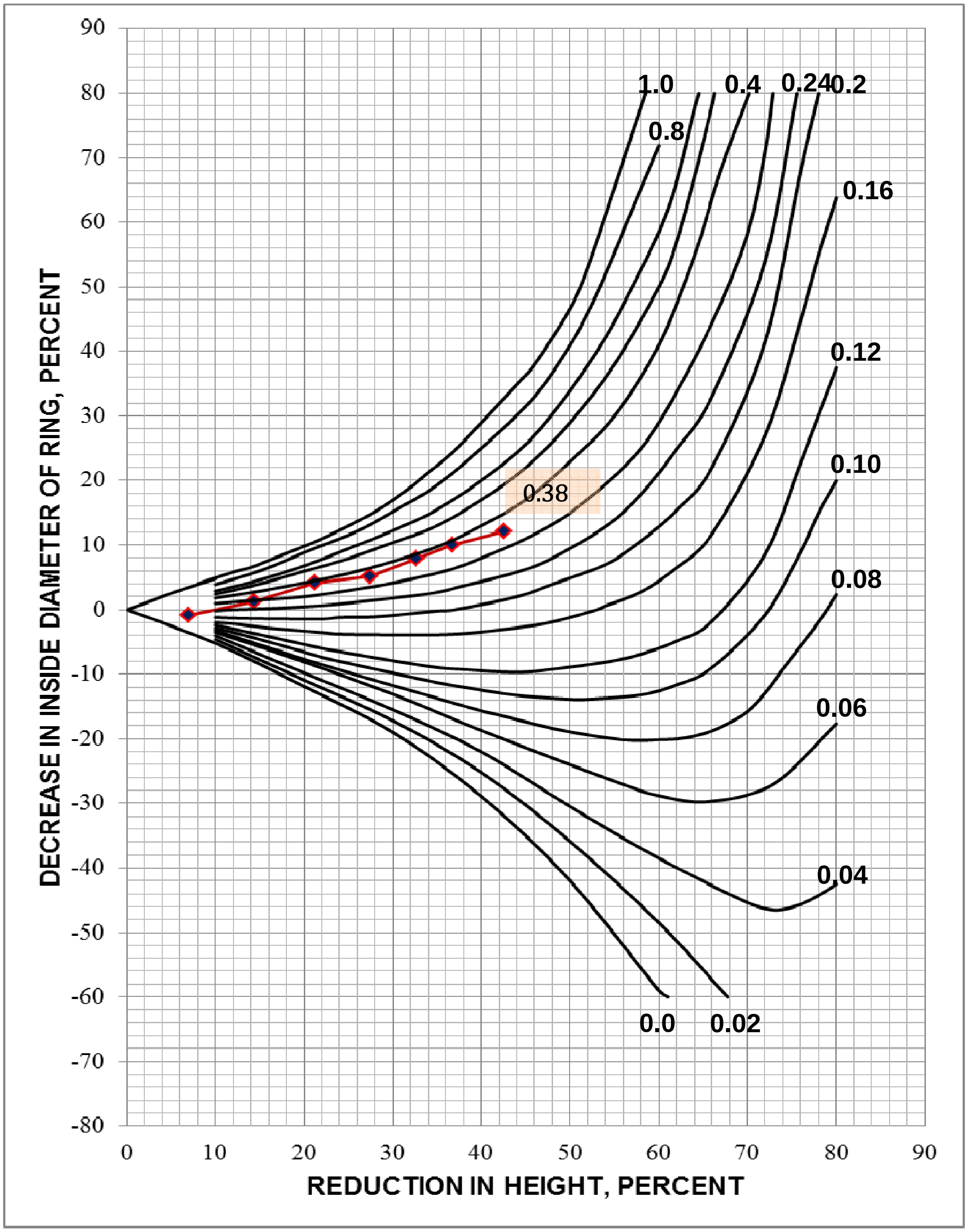


Fig. 4.20: Comparing the Ring test (without lubrication) curve with theoretical standard calibration curve (6:3:2)

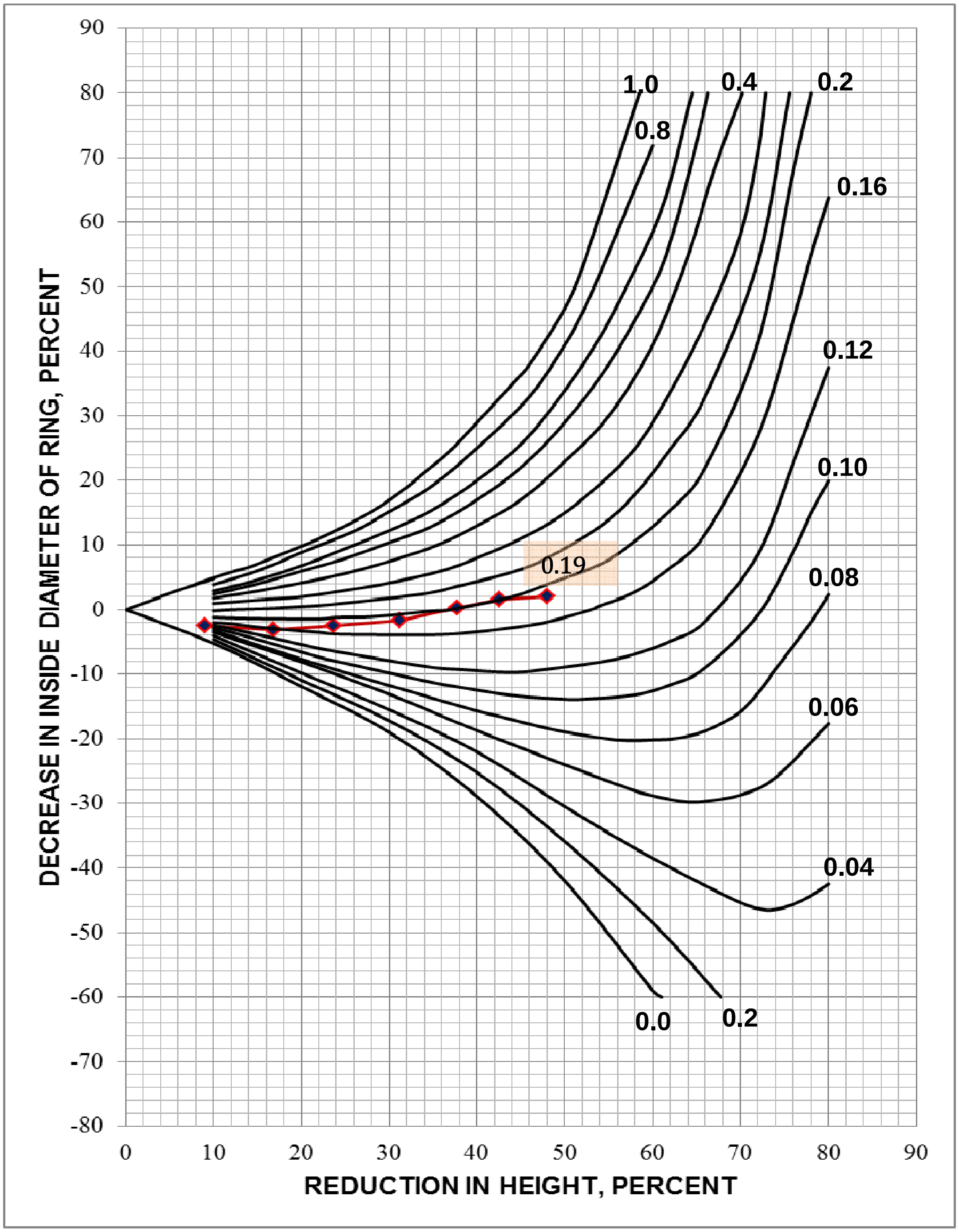


Fig. 4.21: Comparing the Ring test (with lubrication) curve with theoretical standard calibration curve (6:3:2)

4.6 Various stages in the formation of product during Combined extrusion-forging process

Experiments were carried out to manufacture the product Collet chuck holder using combined extrusion-forging process on a Universal testing machine. It is observed that the whole compression process consists of four stages.

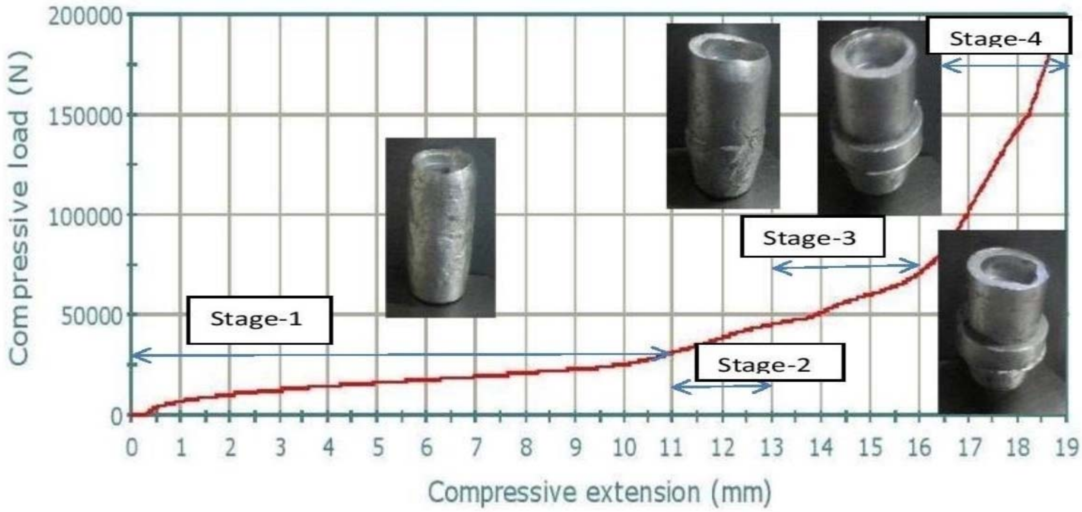


Fig. 4.22: Various stages in combined extrusion-forging process

The different stages in the forming of product shape Collet chuck using combined extrusion-forging process have been shown the experimental graph. The first stage shows the initial compression of the billet. In second stage small indentation hole and forging of the taper die has been completed. In third stage both extrusion and forging are completed. The last circular extrusion part has been completed at this stage. In the fourth stage, flash had come and finishing of the product has been completed. The Figures 4.23 to 4.26 represents the graphs for variation of punch load with punch movement at different punch travel.

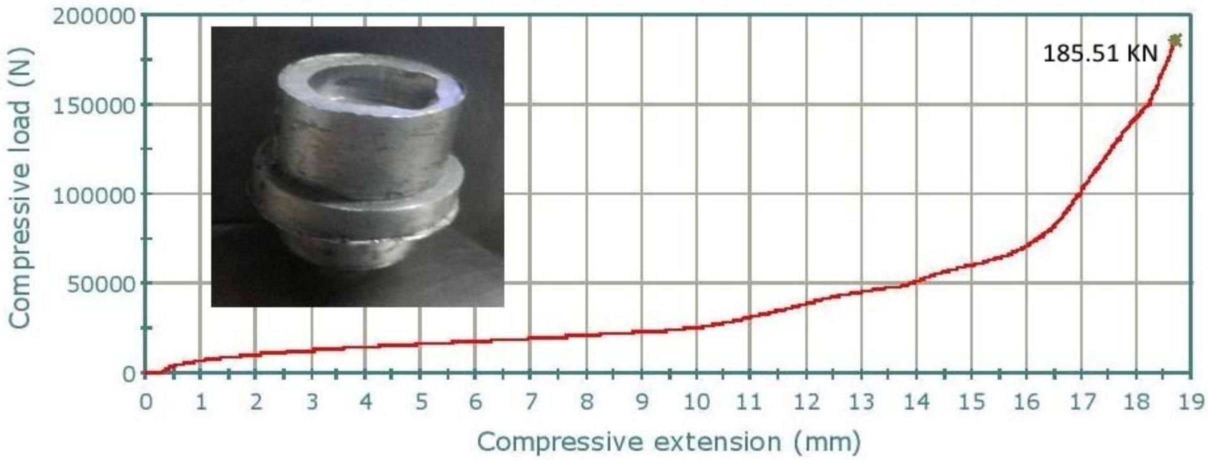


Fig. 4.23: Variation of punch load with stroke for 18.8 mm punch travel

The Fig. 4.23 represents the variation of punch load with respect to punch movement at 18.8 mm length of travel of punch. Here the complete product obtained with flash. In this stage all four stages which are mentioned in the Fig. 4.22 are existed. The load required for complete formation of product is 185.51 KN.

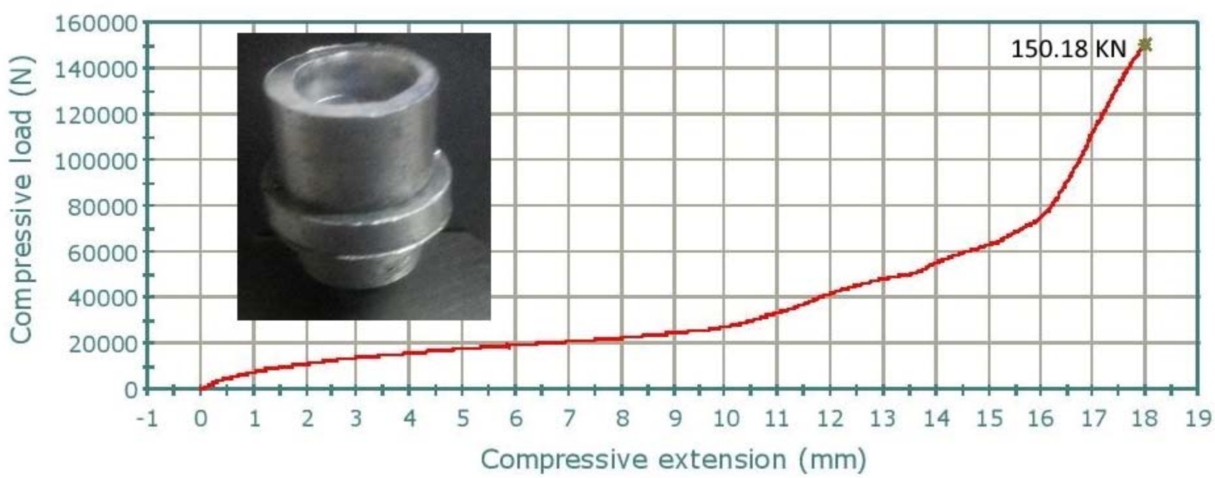


Fig. 4.24: Variation of punch load with stroke for 18 mm punch travel

The Fig. 4.24 represents the variation of punch load with respect to punch movement at 18 mm length of travel of punch. There is not much variation compared to the 18.8 mm punch travel. Here the complete product is obtained and flash just started to come out. The load required at 18 mm of punch travel is 150.18 KN. There is significant variation in load for 18.8 mm and 18 mm punch travel. This is because at 18 mm of punch travel, flash is not formed yet and extrusion part also not completed. So 18.8 mm punch travel takes more load than 18 mm punch travel.

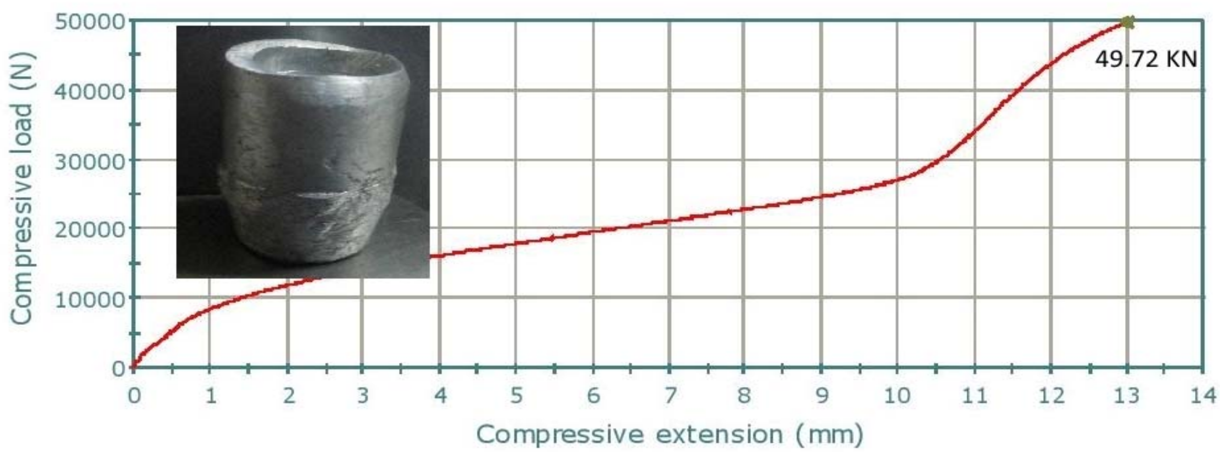


Fig. 4.25: Variation of punch load with stroke for 13 mm punch travel

The Fig. 4.25 represents the variation of punch load with respect to punch movement at 13 mm length of travel of punch. In this stage only complete formation of hole in the first part and partial formation of tapered part is obtained. Circular part with flash and extrusion part are not started. The forming load required at 13 mm punch travel is 49.72 KN.

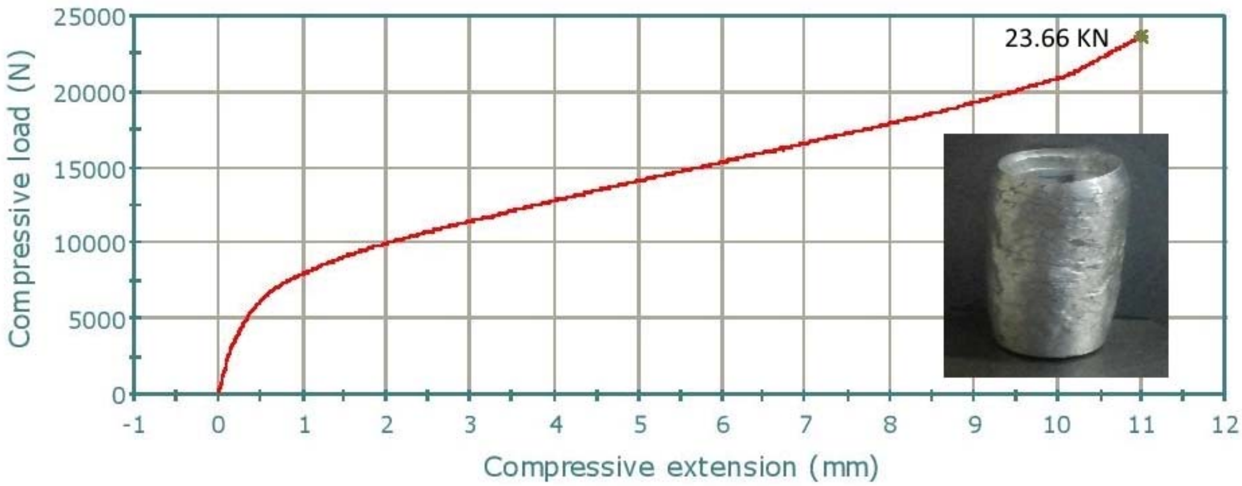


Fig. 4.26: Variation of punch load with stroke for 11 mm punch travel

The Fig. 4.26 represents the variation of punch load with respect to punch movement at 11 mm length of travel of punch. This stage represents only initial compression. The punch head is penetrated into the billet. The load required at 11 mm punch travel is 23.66 KN.

4.7 Conclusion

The experimental analysis has been done for combined extrusion-forging process at different punch movements. The following conclusions obtained after experimental analysis.

- Experimental setup was made for combined extrusion-forging process.
- The maximum forming load has been obtained for different punch movements.
- Flow stress of aluminium has been calculated and friction factor value has been obtained from the ring test.

CHAPTER 5

COMPARISON OF RESULTS

5.1 Comparison of Results

Results are compared for simulation analysis and experimental analysis for validation purpose.

5.1.1. Maximum Forming load of combined extrusion-forging process

Comparison of maximum forming loads for Finite element analysis simulation and experimental analysis are shown in the following Table. 5.1. The maximum percentage error obtained is 22.14%, which is for 13 mm punch movement and the minimum percentage error obtained is 1.5625%, which is for 15 mm punch movement. From these observations, we can tell that there is not much variation in the simulation and experimental results.

Table 5.1 Comparison of maximum forming load (peak load) of a combined extrusion-forging process of different punch movements

Different length of punch movements	Simulation peak load (kN)	Experimental peak load (kN)	Absolute percentage error
11 mm	21.3	23.66	9.9746
13 mm	38.7	49.72	22.14
15 mm	56.7	57.6	1.5625
18 mm	134	150.18	10.773
18.8 mm	145.08	185.51	21.81

5.1.2 Deformed product shape at different punch movements

Experiment and simulation were carried out for product Collet chuck holder through combined extrusion-forging process at different length of punch movements. Same input parameters had taken for both simulation and experimental analysis. Fig. 5.1 shows the product Collet chuck holder at different punch movements for simulation and experimental analysis. In the Fig. 5.1 the products are shown as per the order 11 mm, 13 mm, 15 mm, 18 mm and 18.8 mm length of punch movements from the left side of the diagram. It is shown that initial compression occurred up to 11 mm length of punch travel. After that, up to 13 mm length, punch head penetrated into the billet and small hole will form. At 15 mm length of punch movement tapered part of the product will form. At 18 mm of punch movement, total product Collet chuck holder will form except the flash. At 18.8 mm length of punch movement, the entire product, including flash will form.

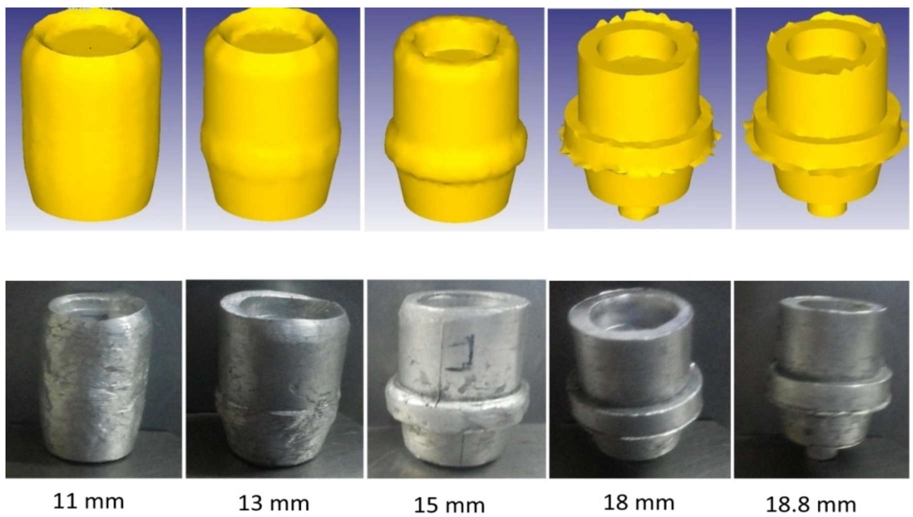


Fig. 5.1: Collet chuck holder at different punch movements for both simulation and experimental analysis

5.1.3 Metal Flow Pattern at Different punch movements

The Fig. 5.2 shows the flow pattern for combined extrusion-forging process at 15 mm and 18 mm punch movements both in simulation and experimental analysis. The grid line distortion indicates that the process utilizes the maximum amount of redundant work and types of deformation in extrusion-forging. The shear distortion requires energy which is not related to the change in shape of the billet to required product. This work is called redundant work. From Fig.5.2 we can observe that the distortion of flow pattern is more at the center of the product. Metal flow is mainly concentrated at the center of the product because of the friction between the billet and die interface. The grid pattern at the center part showing that metal flowing towards the circular part and flash part of the product. The grid pattern at the tapered part is trying to penetrate into the extruded part of the product. The grid pattern of the extruded part of the product we can observe in the 18 mm length of punch movement. The grid distortion at the hole which is at the top of the product is because of the interface friction between billet and punch head.

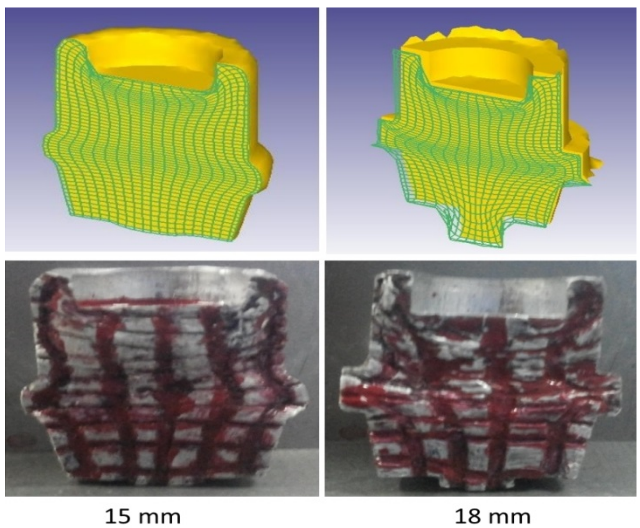


Fig. 5.2: Comparison of flow patterns for both simulation and experimental analysis at 15 mm and 18 mm length of punch movement

5.1.4 Variation of Punch load with stroke at different punch movements

The following Figures 5.3-5.6 represents the graphs between punch load and stroke at different punch movements. From the graphs we can observe that there is not much variation in the forming loads obtained for both simulation and experimental analysis at 11 mm and 13 mm punch movements. The load variation is more at 18.8 mm and 18 mm punch movements. The experimental load is more compared to simulation load because, the interface fiction is more in experimental conditions, practical problems like variation in billet shape and lack of lubricant etc. The graph curves shows the same variation at different punch movements.

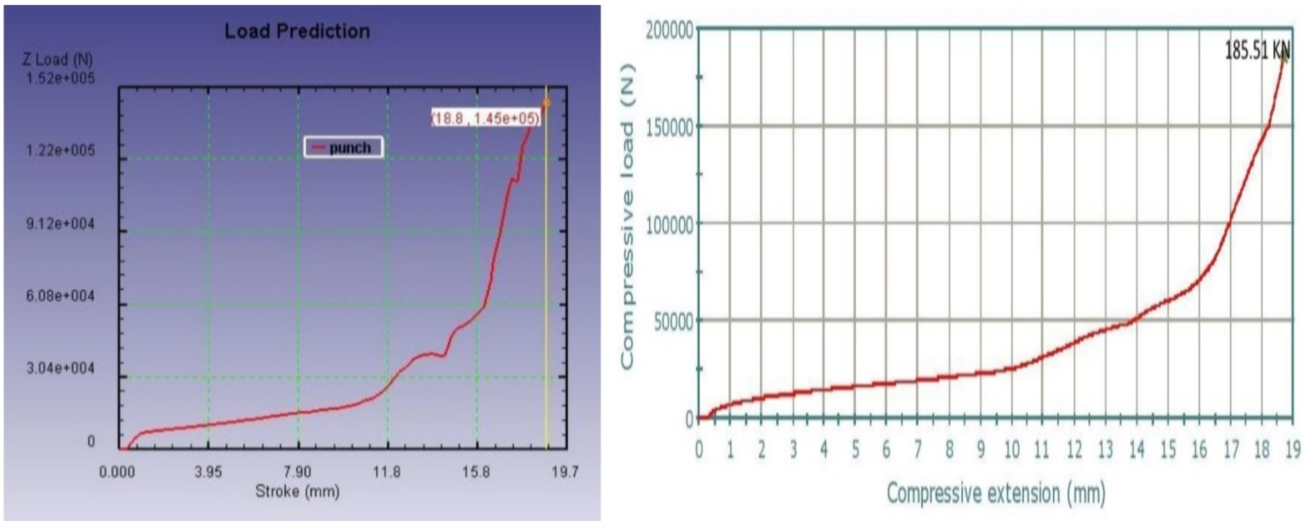


Fig. 5.3: Load vs Stroke graphs at 18.8 mm punch movement for both simulation and experimental analysis

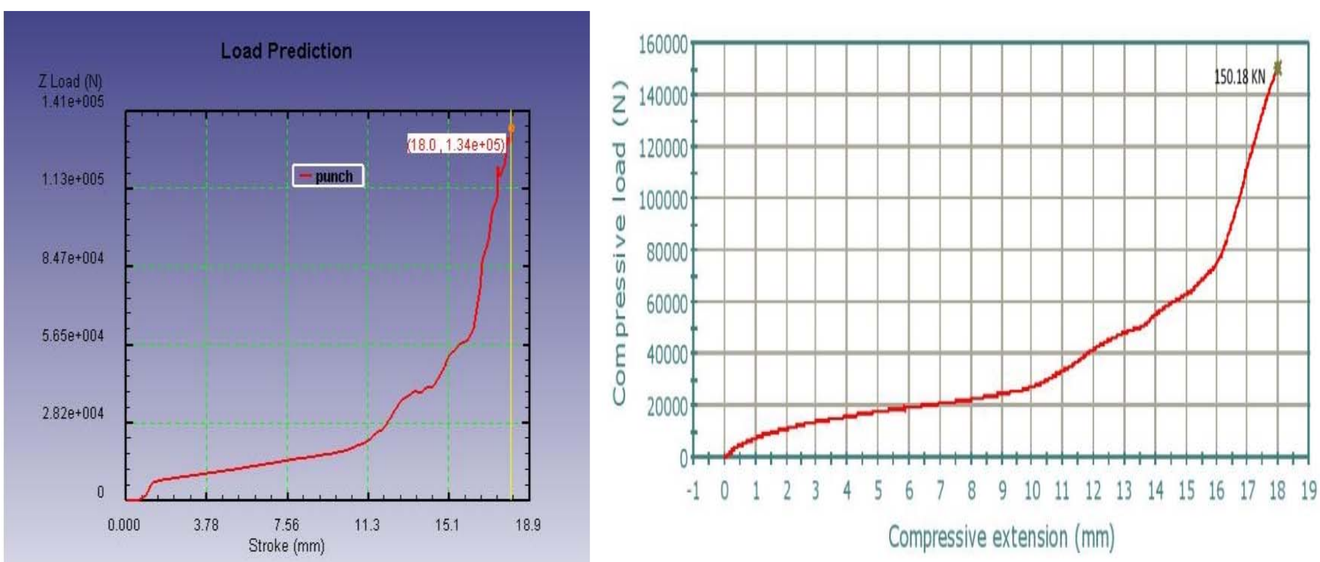


Fig. 5.4: Load vs Stroke graphs at 18 mm punch movement for both simulation and experimental analysis

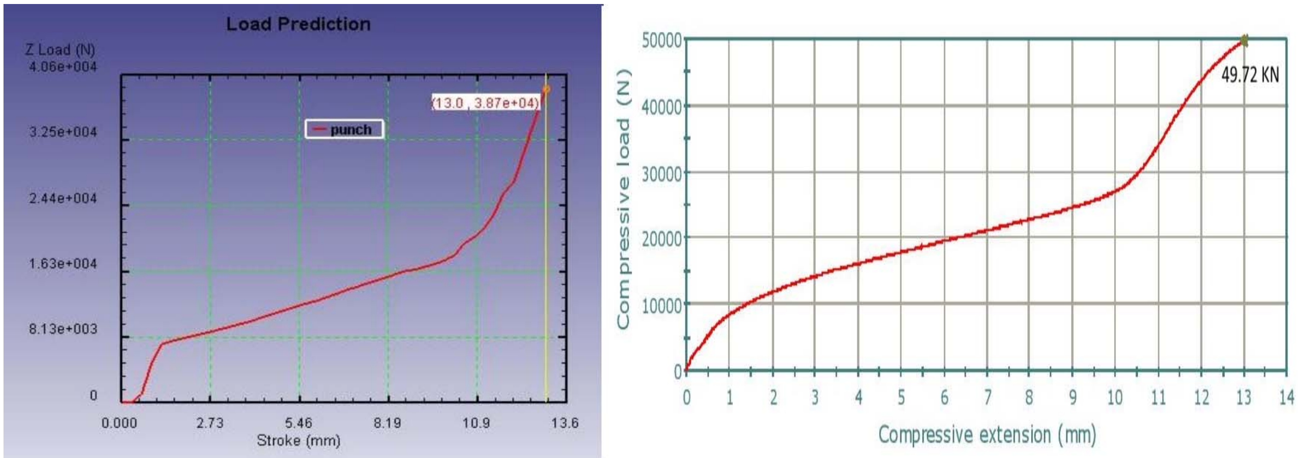


Fig. 5.5: Load vs Stroke graphs at 13 mm punch movement for both simulation and experimental analysis

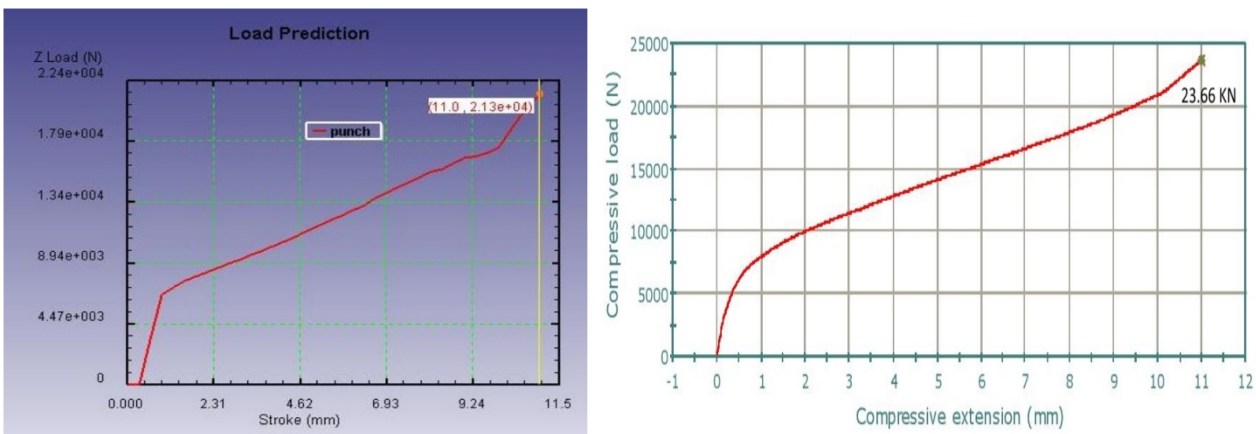


Fig. 5.6: Load vs Stroke graphs at 11 mm punch movement for both simulation and experimental analysis

5.2 Conclusion

The experimental die filling, metal flow pattern and load requirements at different punch movements valid well with the FEM analysis results. The grid lines in flow pattern show that metal flow homogeneous with friction interfaces. The peak loads at different punch movements had been compared for both FEM and experimental analysis. From the Figures 5.3-5.6 we can observe that there is good agreement between FEM analysis and experimental results.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusions

In present research work, FEM simulation and experimental analysis have been done for the product collet chuck holder. Experimental results are in good agreement with simulation results. From the obtained results, we can draw some conclusions

1. Finite element based 3D simulation software DEFORM 3D was implemented on combined extrusion-forging process to analyze effective stress, effective strain, total velocity and metal flow patterns.
2. Experiment and simulation are carried out for different punch movement (length of travel of punch) by that we can know the metal filing in dies.
3. Experimental setup for combined extrusion-forging process of Collet chuck holder had been made.
4. Flow stress of aluminum has been calculated and friction factor value is obtained from the ring test on a universal testing machine.
5. The obtained variation of punch load with respect to displacement curves from experiment shows good agreement with the simulation load.
6. The experimental die filling, metal flow pattern and load requirements are in good agreement with simulation results.

6.2 Scopes for Future work

The present research work can be extended further to explore the more aspects of combined extrusion-forging process. The following are the some of the recommendations for future work

- This method extended to do in the hot conditions with other materials.
- Upper bound analysis can be done to verify the results obtained from the experimental analysis.
- The proposed Finite element analysis can be extended to apply for the determination of die stresses.
- This method can be further extended to do analysis for other materials and complicated shapes.

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